[19] 中华人民共和国国家知识产权局

[51] Int. Cl⁷
G02B 27/10
G02B 27/28 H01L 21/324
H01S 3/00

[12] 发明专利申请公开说明书

[21] 申请号 03108378.1

[43] 公开日 2003 年 10 月 15 日

[11] 公开号 CN 1448753A

[22] 申请日 2003.3.28 [21] 申请号 03108378.1

[30] 优先权

[32] 2002. 3.28 [33] JP [31] 091440/2002

[32] 2002. 3.28 [33] JP [31] 091454/2002

[32] 2002. 3.28 [33] JP [31] 091468/2002

[71] 申请人 三菱电机株式会社

地址 日本东京

[72] 发明人 岡本達樹 森川和敏 佐藤行雄 西前順一 小川哲也

[74] 专利代理机构 中国国际贸易促进委员会专利商标事务所

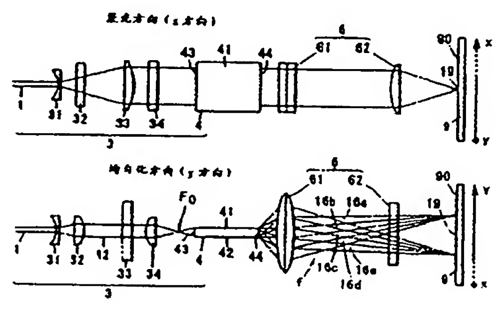
代理人 王以平

权利要求书 3 页 说明书 27 页 附图 31 页

[54] 发明名称 激光束均匀照射的光学系统

[57] 摘要

激光束均匀照射的光学系统，包括：把来自光源的激光束在空间上分割为分割束的波导；把分割束重合照射在照射面上的重合用透镜；使照射面上的光束强度均匀的延迟板。 波导使分割束宽度为激光束截面上的空间干涉距离的 1/2 倍以上；延迟板使分割出的彼此相邻的分割束间延迟比该激光束的时间的干涉距离还长，减轻照射面上的干涉。另一光学系统包括：把激光束分割为分割束的激光束分割部件；把分割束重合照射在照射面上的重合照射部件；使照射面上的光束强度均匀的均匀化部件。 均匀化部件包括：使分割出的彼此相邻的分割束之间延迟比该激光束的时间的干涉距离还长的光学延迟部件，还可包括：使分割出的彼此相邻的分割束之间偏振方向实质上正交的旋光部件。



ISSN 1008-4274

知识产权出版社出版

1. 一种激光束均匀照射的光学系统，包括：把来自激光光源的激光束在光束截面中、在空间上分割为分割束的激光束分割部件；以及

把分割束重合照射在照射面上的重合照射部件；

其特征在于：所述激光束分割部件使所述的分割束宽度大于、等于激光束截面的截面方向的空间干涉距离的1/2倍。

2. 根据权利要求1所述的光学系统，其中：所述的激光分割宽度大于、等于空间干涉距离。

3. 一种激光束均匀照射的光学系统，包括：把来自激光光源的激光束在光束截面中、在空间上分割为分割束的激光束分割部件；

把分割束重合照射在照射面上的重合照射部件；以及

使照射面上的光束强度均匀的均匀化部件；

其特征在于所述均匀化部件包括：使所述分割的光束的彼此相邻的相邻分割束的一方相对于另一方延迟比该激光束的时间的干涉距离还长的光学延迟部件。

4. 根据权利要求3所述的光学系统，其中：所述光学延迟部件是配置在把多个分割束在空间上分离的区域中的延迟板，使该空间上分离的相邻分割束中的某一束透过。

5. 根据权利要求4所述的光学系统，其中：所述激光束分割部件是具有彼此相对的反射面的一维方向的波导，所述重合照射部件包括把来自激光束分割部件的分割束复制到照射面上的复制透镜，以及各延迟板配置在分割束的复制透镜的焦点位置附近。

6. 根据权利要求5所述的光学系统，其中：配置入射激光的光轴相对于波导与其反射面间的中心轴斜交，使得在反射面间不产生不反射而通过的光，使彼此相邻的两组照射光束的任意一个通过单一的延迟板。

7. 根据权利要求4所述的光学系统，其中：所述激光束分割部件是一维分割激光束的分割用的柱面透镜阵列；

所述延迟板被配置在空间上分离了由所述的分割用的柱面透镜阵列形成的多个分割束的区域中，使彼此相邻的分割束的任意一个透过.

8. 一种激光束均匀照射的光学系统，包括：把来自激光光源的激光束在光束截面中、在空间上分割为分割束的激光束分割部件；

把分割束重合照射在照射面上的重合照射部件；以及

使照射面上的光束强度均匀的均匀化部件；

其特征在于所述均匀化部件包括：使所述分割了的光束的彼此相邻的相邻分割束的一方相对于另一方的偏振方向实质上正交的旋光部件。

9. 根据权利要求8所述的光学系统，其中：所述旋光部件是被配置在空间上分离了多个分割束的区域中的旋光部件，用于使该空间上分离的相邻分割束的任意一方的偏振方向实质上正交.

10. 根据权利要求8或9所述的光学系统，其中：所述激光束分割部件是具有彼此相对的反射面的一维方向的波导，所述重合照射部件包含把来自激光束分割部件的分割束复制到照射面上的复制透镜，以及所述旋光板配置在分割束的复制透镜的焦点位置附近.

11. 根据权利要求10所述的光学系统，其中：入射激光的光轴与所述波导的反射面间的中心轴斜交，使在反射面间不产生不反射而通过的分割束.

12. 根据权利要求8或9所述的光学系统，其中：所述激光束分割部件是一维分割激光束的分割用的柱面透镜阵列，所述旋光板被配置在空间上分离了由分割用的柱面透镜阵列形成的多个分割束的区域中，使彼此相邻的分割束的任意一方相对于另一方的偏振方向正交。

13. 根据权利要求8或9所述的光学系统，其中：配置了插入到所述另一方的分割束中，用于使另一方的分割束的光程长与所述一方的分割束的光程长实质上相同的光程长补偿板.

14. 一种激光束均匀照射的光学系统，包括：把来自激光光源的激光束在光束截面中、在空间上分割为分割束的激光束分割部件；以及

把分割束重合照射在照射面上的重合照射部件；

其特征在于：所述重合照射部件使各分割束在照射面上彼此位移、复制，形成照射光束。

15. 根据权利要求 14 所述的光学系统，其中：所述激光束分割部件包含具有彼此相对的反射面的一维方向的波导或分割用的柱面透镜阵列，以及所述重合照射部件是具有透镜像差的柱面透镜。

激光束均匀照射的光学系统

技术领域

本发明涉及对被照射物激光处理（laser treatment）时、改善了照射面上的照射激光束（laser beam）的强度分布的均匀性的激光束均匀照射用的光学系统。

背景技术

作为使用了激光照射的热处理的例子，我们知道在制造多晶硅膜时，预先在适当的衬底（例如玻璃衬底）上通过化学气相淀积法（CVD）等的气相淀积（vapor deposition）法形成非晶体的硅膜，用激光束扫描该非晶硅膜而进行多晶化的方法。例如美国专利 USP5，529，951 公开了在半导体集成电路的组装中，通过再向电路构成部分蒸镀非晶硅，向必要的地方照射受激准分子（excimer）激光束，在多晶硅层上形成非晶体的方法。该美国专利为了增大照射面区域，在光学系统中使用蝇眼透镜或棱镜作为均匀化手段，使受激准分子激光束的强度分布在整个近正方形的区域中均匀化。

我们还知道在大面积的衬底上使硅膜多晶化的方法，例如通过透镜把来自激光光源的激光束聚光在非晶硅膜上进行照射，在照射时，使激光点在硅膜上扫描，一边局部地使其熔化，一边在凝固的过程中使硅结晶。在使用的激光束中，在照射位置的光束的轴向强度分布依赖于激光源的光束轮廓，通常是对光学轴为轴对称的高斯分布。通过这样分布的光束的照射而形成的多晶硅膜向表面方向的结晶的均匀性非常低，很难在薄膜晶体管制造中把它作为半导体衬底使用。

此外，还知道使波长短的受激准分子激光在照射面上的光束轮廓为矩形，掠过半导体膜上进行加热的技术。在日本专利公开 11-16851 和日本专利公开 10-333077 中，把来自振荡器的激光束通过在垂直于

光轴的面内彼此交叉的两个柱面透镜阵列后，通过配置在其前方的聚焦透镜，在半导体膜表面上成像. 柱面透镜阵列把多个微小柱面透镜配置为彼此平行，并且垂直于光轴，是把一条光束分割为多条光束的光学元件.

上面所述的方法使采用高斯分布或单纯模式的激光束通过两个柱面透镜阵列，在正交的两个方向上成为均匀的强度分布. 照射光束在半导体膜等的照射表面上的形状在半导体表面上正交的两个方向上具有不同的宽度. 该方法通过使照射的激光束在窄的一方的宽度方向扫描移动，在半导体膜上反复形成了具有相当于长的一方的宽度的宽度一定的多结晶区域.

可是，如果通过这样的柱面透镜阵列分割来自激光光源的激光束，再在照射面上合成，则照射面上产生激光的光干涉，在照射位置，形成具有光束强度高和光束强度低的地方来回重复的干涉图案.

由于由重合了的多个光束在照射面上产生的干涉影响到照射面上结晶的生长. 即，当使用照射面上的照射光束的形状为长方形的照射激光束来加热非晶体半导体膜、使其结晶化时，因为使照射光束在窄的宽度方向移动，所以与移动方向正交的长度方向的强度分布严重影响结晶的生长，该方向的强度分布不均匀、干涉图案大，这对于使硅膜的结晶粒长大是不利的.

提出了几种去掉由于这种干涉引起的激光照射强度的不均匀性的方法. 在日本专利公开 2001-127003 中公开了通过平行光管（collimator）使来自光源的激光束成为平行光，照射到反射面为阶梯状的镜子上，使通过该多级镜分割的光束通过合成柱面透镜阵列和汇聚用的柱面透镜阵列，照射到照射面上. 该光学系统通过各反射面间的阶梯，为分割的光束设置比激光束的可干涉长度长的光程差，防止照射面中的分割光束之间的干涉.

另外，日本专利公开 2001-244213 号公开了通过光束平行光管使来自光源的激光束成为平行光后，照射到多个小的反射镜上，把来自各反射镜的反射光照射到照射面上，使其重合，所以通过确保经各平

面镜反射的激光束的光程差在可干涉长度以上，同样防止了干涉。

上面所述的光束的均匀化技术利用具有多个反射面的反射镜来设置光程差，防止因分割来自同一光源的激光束，而在照射面上重合时发生的干涉，可是这些光学系统需要特殊的反射镜。特别是特开2001-244213的光学系统需要使基于反射镜的光学系统的光轴弯曲的配置。为了能使多个分割的各光束正确地照射到照射面，要求光学系统的各反射镜满足特定的位置关系的配置。因此，多个反射镜的配置变得复杂，存在应该作为热处理装置而配置的光学系统的自由度降低的问题。特别是对全部的分割束设置光程差时，对于时间的干涉距离大的激光振荡源，装置变得又大又变复杂，这是不现实的，而且光学调整也困难。

发明内容

鉴于上述的问题，本发明的目的在于提供一种激光束均匀照射的光学系统，这种光学系统通过使分割了来自光源的激光束的各光束在照射面上重合，是在照射面上形成具有均匀的强度分布的照射光束的光学系统，它可以防止重合引起的分割束间的干涉，能谋求照射光束的均匀化。

本发明的其他目的在于提供一种均匀照射的光学系统使用于防止这样的干涉、使照射光束均匀化的结构和调整变得简单并且容易。

本发明的别的目的在于提供一种光学系统，它适用于作为被照射物的非晶硅膜中使其多晶化的激光加热装置，能制造在结晶区域上晶格缺陷少的多晶硅膜。

本发明的均匀照射激光束的光学系统由以下部分构成：在光束截面中、把来自激光光源的激光束在空间上分割为分割束的激光束分割部件；把多个被分割的光束重合照射在照射面上的重合照射部件；使照射面上的光束强度均匀的均匀化部件。所述激光束分割部件使分割的光束宽度为来自光源的激光束截面的截面方向的空间干涉距离的1/2倍以上。规定为这样的光束宽度的分割束即使通过重合照射部件在

照射面上重合，也减轻了多个光束的相互干涉，使照射面上的照射强度的分布均匀。

该激光束均匀照射的光学系统除了包括在光束截面中把来自激光光源的激光束在空间上分割为分割束的激光束分割部件和把分割的光束重合照射在照射面上的重合照射部件外，还包含使照射面上的光束强度均匀的均匀化部件．一种所述的均匀化部件包含使所述分割的光束的彼此相邻的相邻分割束中的一方相对于另一方延迟了比该激光束的时间的干涉距离还长的光学延迟部件，用于防止彼此相邻的分割束间在照射面上发生干涉，使照射强度分布均匀化。

作为本发明别的均匀化部件，包含：使由激光束分割部件分割的彼此相邻的分割束间的偏振角度实质上正交的旋光部件．旋光部件通过使分割了的光束间的偏振角度彼此正交，减轻照射面上使各相邻的分割束重合时会产生的分割束间的干涉，使照射强度分布均匀化．

本发明的光学系统通过同时减少所述激光束的截面方向的空间的干涉距离的要素和光轴方向的时间的干涉距离的要素，具有能使照射强度分布极其均匀的优点。

本发明中，重合照射部件包含：使各分割的激光束在照射面上彼此位移或彼此错开，形成复制的照射光束．通过分割部件分割为多个的各分割束在通过重合照射部件时，在光学上错开，照射到照射面上，降低了照射面上分割束间的干涉．用于使该复制位移或错开的重合照射部件能简单地实施，能同时使用防止所述空间的干涉距离的要素和光轴方向的时间的干涉距离的要素引起的干涉的部件．

本发明的所述激光束均匀照射的光学系统把照射面作为形成在衬底上的非晶体或多晶体的半导体膜，能用作半导体膜退火用光学系统．

附图说明

下面简要说明附图．

图 1A 和 1B 是表示利用了本发明的波导的实施例的激光束均匀照射的光学系统的配置的图，分别表示从 y 方向观察的图和从 x 方向观

察的图.

图 2 是说明波导的激光束的分割形态的剖视图.

图 3A 表示激光束在波导中分割时，应该分割的激光束的截面中的分割束的配置，图 3B 表示波导出射端面中的分割束的配置.

图 4 是表示由波导分割出的彼此相邻的两个分割束在照射面上重合时的合成照射光束的强度分布和可见度的图（d=s 时）.

图 5 是说明激光束的空间的干涉距离 s 的定义的图.

图 6 是表示由波导分割为 7 束的分割束在照射面上重合时的合成照射光束的强度分布和可见度的图（d=s 时）.

图 7 是表示激光束的光程差和可见度的关系的曲线图.

图 8A 和图 8B 是表示使用了柱面透镜阵列作为本发明的激光束分割部件的其他实施例的激光束均匀照射的光学系统的配置的与图 1A 和图 1B 相当的图.

图 9A 表示使用分割用柱面透镜阵列作为激光束分割部件，应该分割的激光束的截面中的分割束的配置，图 9B 同样表示波导出射端面中的分割束的配置.

图 10 是表示由分割用柱面透镜阵列分割的彼此相邻的两个分割束在照射面上重合时的合成照射光束的强度分布和可见度的图（d=s 时）.

图 11 是表示由分割用柱面透镜阵列分割为 7 束的分割束在照射面上重合时的合成照射光束的强度分布和可见度的图（d=s 时）.

图 12A 和 12B 表示与本发明的实施例相关，使用波导作为分割部件，利用了透光性的延迟板 7 作为光学延迟部件的激光束均匀照射的光学系统的与图 1A 和图 1B 同样的图.

图 13 是图 12 所示的光学系统的变形例，表示遮断了在波导的反射面之间不反射而通过的分割束的形态的光学系统与图 12B 同样的图.

图 14 是表示本发明的其他实施例的激光束均匀照射的光学系统的配置的和图 12B 同样的图，表示入射光的光轴和波导中心轴斜交的

配置。

图 15 是表示入射光的光轴和波导中心轴斜交的配置中的光束分割的与图 14 同样的图。

图 16A 和 16B 是说明斜交配置了入射光的光轴和波导中心轴的图 15 所示的波导中的激光束的分割状态的与图 3A 和图 3B 同样的图。

图 17 是表示本发明的其他实施例的激光束均匀照射的光学系统的配置的图，其配置为波导的入射面与波导中心轴斜交。

图 18A 和 18B 表示关于本发明的其他实施例的激光束均匀照射的光学系统，对分割用的柱面透镜阵列应用了延迟板的与图 8A 和图 8B 同样的图。

图 19 表示在复制用柱面透镜阵列的前后配置了两块延迟板的与图 18B 同样的图。

图 20 是对复制用柱面透镜阵列进行焦点调制的与图 18B 同样的图。

图 21A 和图 21B 表示关于本发明的其他实施例的激光束均匀照射的光学系统，使用波导作为分割部件、使用旋光板作为均匀化部件的例子，分别是与图 1A 和图 1B 同样的图。

图 22 是图 21B 的光学系统的变形例，表示遮断了在波导的反射面之间不反射而通过的分割束的形态的光学系统的与图 21B 同样的图。

图 23 是表示本发明的其他实施例的激光束均匀照射的光学系统的配置的与图 21B 的同样的图，表示入射光的光轴和波导中心轴斜交的配置。

图 24 是表示入射光的光轴和波导中心轴斜交的配置中的光束分割的与图 23 同样的图。

图 25 为图 21 的变形例，表示包含半波长板和光程长补偿部件的激光束均匀照射的光学系统。

图 26 为图 23 的例子的变形例，表示包含半波长板和光程长补偿部件的激光束均匀照射的光学系统。

图 27A 和 27B 表示应用了分割用柱面透镜阵列和半波长板的与图

1A 和图 1B 同样的图.

图 28 表示对图 27A 和 27B 所示的分割束交替配置了半波长板和延迟板的光学系统的与图 27B 同样的图.

图 29 表示在复制用柱面透镜阵列的前后配置了两个延迟板的与图 27B 同样的图.

图 30A 和 30B 是关于本发明的其他实施例，表示重合照射部件使各分割束在照射面上彼此位移，即错开、复制的激光束均匀照射的光学系统的配置的图，分别表示从 y 方向观察的图和从 x 方向观察的图. 图 30C 是表示图 30A 和 30B 所示的光学系统的照射光束强度的轮廓的图.

图 31A、31B 和 31C 表示入射光的光轴和波导中心轴斜交配置的分别与图 30A、30B 以及 30C 同样的图.

图 32A 和 32B 是具有在照射面上使分割束位移、复制的重合照射部件的分别与图 8A 和图 8B 同样的图.

图 33A 和 33B 是具有在照射面上使分割束位移、复制的重合照射部件的分别与图 18A 和图 18B 同样的图.

图 34 是具有在照射面上使各分割束位移、复制的重合照射部件的与图 27 同样的图.

具体实施方式

本发明的光学系统的激光束分割部件使从激光光源发出的单一激光束分割出的多个分割束通过重合部件，使分割束被重合照射到照射面上. 这里激光束分割部件关于多个分割束，使各光束宽度为激光束截面上的截面方向的空间的干涉距离的 1/2 倍以上，据此，防止在照射面上的分割束间的干涉，照射光束的强度分布能均匀化.

在光束被分割前，两个分割束在该激光束的截面内是彼此相邻的时，容易发生分割束间的干涉，但是通过使各分割束宽度为空间的干涉距离的 1/2 倍以上，就能降低相互干涉.

把上述的各分割束的光束宽度规定为激光束分割部件的出射面中

的分割束的宽度，这时空间的干涉距离是指来自光源的激光束投射到该出射面的位置时、在截面内的空间的干涉距离。后面将详细描述，该空间的干涉距离是指激光束被分为两支，然后由于在照射面上再次重合时发生的干涉，后面描述的可见度（visibility）变为 1/e 时的两个光束的最小重叠距离。

在本发明中，分割束宽度与光束截面中的截面方向的空间的干涉距离的比为 1/2 以上，但是 $1/\sqrt{2}$ 以上较好，在 1 以上更好。即，由激光束分割部件分割的分割束的宽度希望设定为空间的干涉距离的 $1/\sqrt{2}$ 以上，特别是 1 倍以上。

分割束宽度的上限由分割激光束的分割数决定，但是分割的光束的数量至少是 5，希望在 7 以上。尽管分割数越大对照射的激光束的强度的平坦化就越有效，但是不希望分割数大到使所述分割束宽度与空间的干涉距离的比变为低于 1/2。实用的分割数为 5~7，分割束宽度对于空间的干涉距离设定为 1 倍以上。

激光束分割部件分割来自激光源的激光束，并且规定所述的激光束宽度，但是该分割部件能使用波导或柱面透镜阵列。它们都是只在垂直于光轴的面中的任意一个方向把激光束分割成所述分割数的分割束。

波导能利用具有彼此相对的反射面的中空体和实心的透光体。中空的波导能利用在空间中把两个镜面以一定间隔相对配置的物体。

实心的波导是透明的板状，把两方的主面作为镜面，把两方的端面用于入射和出射的透光体。这样的波导通常能利用光学玻璃板。

在波导中，在激光束分割部件中包含用于使来自激光源的射出激光束入射到波导内的反射面间的聚光透镜。

从波导的出射面能得到：在反射面不反射而透过波导内的分割束；和每次在相对的反射面上反射的两组的分割束。入射光束在反射面反射的次数每增加一次，分割束就增加两个。

而作为激光束分割部件的柱面透镜阵列是使柱状、截面为凸透镜状的多个柱面透镜平行排列在与光轴实质上正交的一个方向上。能对

应于每个微小的柱面透镜得到的分割束. 在使用柱面透镜阵列的激光束分割部件中，希望包含向柱面透镜阵列入射平行光的平行光管.

本发明的光学系统的其他形态在光学系统中包含均匀化部件，在均匀化部件中包含光学延迟部件和旋光部件.

在本发明中，光学延迟部件具有使通过所述激光束分割部件分割的光束中彼此相邻的分割束的一方相对于另一方，延迟比该激光束的时间的干涉距离还长的功能，据此，在照射面上，降低乃至防止彼此相邻的分割束之间的干涉.

光学延迟部件最好利用延迟光束用的透光体，即延迟板，将其插入通过所述激光束分割部件分割的各分割束彼此在空间上分离的光路中. 这时，在把各分割束反过来向来自光源的单一的激光束投影时，彼此相邻的分割束中至少任意一方中插入延迟板，在彼此相邻的分割束之间在光学上设置光程差.

延迟板使分割的相邻的光束的光程差比该激光束的时间的干涉距离大，据此，防止分离的多个分割束照射到照射面、使其重合时的分割束间的干涉. 光程差由延迟板的厚度即光束透过长度、延迟板的折射率和空气的折射率的差来决定.

以来自激光源的激光束为基准，把延迟板插入从该激光束分离出的相邻的分割束的每隔一个的排列中，彼此产生光程差，从而产生相位差.

本发明中，均匀化部件还包含旋光部件，旋光部件使由激光束分割部件分割出的相邻的分割束间的偏振角度实质上正交，在照射面上重合，形成具有所需要的均匀的强度分布的轮廓的照射光束. 在本实施例中，通过使分割的光束间的偏振角度彼此正交，减少当在照射面上各相邻的分割束重合时会产生的分割束间的干涉，使照射强度分布均匀化.

以来自激光源的激光束为基准，把旋光板插入从该激光束分离出的相邻的分割束的每隔一个的排列中，使彼此在偏振面间产生约 90°的角度.

旋光部件的一个例子是使用水晶的结晶板，该结晶板使透过的光束的偏振面相对于另一方的分割束的偏振面几乎旋光 90°。这样的旋光部件称作半波长板。这里，所谓的实质上正交，包含从一方的分割束的偏振面与另一方的分割束的偏振面正交时的角度有 ±30°的偏移也行。这样，即使两个光束的偏振面不正交，而是斜交，也能降低两个光束间的实质上的干涉。

其他的旋光部件，还能利用菲涅耳菱面体（fresnel rhomb）。

此外，由于只在彼此相邻的分割束中的所述一方的分割束中插入旋光部件，由此相对于另一方的分割束产生光程差，该光程差使在照射面上产生这些分割束的成像位置的偏移。因此，在所述另一方的分割束中插入光程长补偿板，希望使不插入所述旋光部件的另一方的分割束的光程长与该一方的分割束的光程长实质上相同。据此，能使照射面上的所述一方和另一方的分割束的成像鲜明，能有助于合成的照射光束强度分布的均匀化。

关于所述的均匀化部件即延迟板和旋光板的配置，重合照射部件包含把来自激光束分割部件的分割束复制到照射面上的复制（像传递）透镜，当形成了复制透镜把多个分割束在空间上分离了的区域时，延迟板等的均匀化部件被插入这样的分离区域中。例如当激光束分割部件为波导时，延迟板通过复制透镜被配置在各分割束汇聚的焦点位置上。

关于均匀化部件的简化，希望波导的构造或配置不产生不反射而通过的分割束。该配置如后所述，通过在预定组的分割束中插入单一的延迟板或旋光板，在另一组的分割束中不插入，能减轻照射面上的干涉。它具有能使单一的光学延迟部件的配置简便的优点。

为此，希望只在入射激光束在内反射面不反射而通过波导的分割束中插入遮蔽体。

其他的形态能采用使向波导入射的激光束对于波导中心轴非对称地入射的构造。因此，波导中，使对于波导的入射激光束的光轴与所述的波导的反射面间的中心轴斜交，据此，能不产生在哪个反射面上

都不反射而通过的分割束.

别的形态在波导中使用上面所述的实心透光体，可是，采用该波导的入射面和波导的中心轴斜交的结构，能用斜交的入射面使入射光折射.能使入射光束至少在反射面反射一次，构成分割束.在这些形态中，与遮断不反射就通过的分割束的结构相比，具有能在照射中利用所有的分割束的优点.

当激光束分割部件为柱面透镜阵列时，因为各柱面透镜阵列的出射一侧光路彼此分离，所以均匀化部件的别的配置能把延迟板或旋光板配置在光束的光程上.这时，能把几个小的延迟板或旋光板配置在由柱面透镜阵列分割的成列的光束的每隔一个中.

这样，多个分割束的一部分透过均匀化部件，重合照射部件把分割束重合照射在照射面上，照射的激光的形状投影为矩形或直线状，照射的光束的长度方向的强度分布变为一样.

本发明的实施例中，重合照射部件还包含：在照射面上使各分割激光束彼此错开、复制，形成照射光束的功能.重合照射部件把通过分割部件分离的分割束重合照射在照射面上，使其在照射面上成为矩形或直线状，但是在本实施例中，通过把几个分割束在照射光束的形状的长度方向错开，特别是消除了长度方向的两侧产生的强度的强弱分布.这样的重合照射部件最好能利用具有透镜像差的柱面透镜.

本发明的这些实施例的激光束均匀照射的光学系统适用于：用于把在玻璃衬底上通过化学气相淀积法等而覆盖形成的非晶硅或多晶硅的薄膜加热熔化，进行多晶化或使生长成更粗大的结晶的退火（annealing）装置中.这里，退火不仅是对固体膜照射激光，直接进行结晶化或再结晶，还包含：用激光照射使固体膜暂时熔化，在之后的熔化膜的凝固过程中使其结晶.

在本发明中，激光源包含固体激光器和半导体激光器，激光束包含固体激光和半导体激光的基波和高次谐波.特别是当照射面是硅半导体膜，尤其是非晶硅膜时，除了Nd:YAG激光器、Nd:YLF激光器、Yb: YAG激光器等的固体激光器的基波，希望利用第二高次谐波（2

倍波)或第三高次谐波(2倍波)照射。当这些高次谐波为于350~800nm的波长区域时，所述非晶膜能适度地吸收光束，高效地加热熔化。

特别是在上述的退火用光学系统中，在硅薄膜表面上，形成细的宽幅状的线状的照射激光，通过在与光束线正交方向上扫描，在照射光束通过时，以该光束的宽度扫描硅薄膜，均匀、急速地加热，在光束通过后放置冷却时，能在凝固过程中使其结晶生长，光束的干涉图案少，强度分布均匀，所以能制造各结晶具有宽幅的长的形状和均匀的高结晶性的结晶硅膜。

实施例1

在本发明的实施例1中，图1A和图1B表示激光束均匀照射的光学系统，但是表示了该光学系统在照射面上，形成在y方向以均匀的分布扩展，在x方向汇聚为线状的直线状的照射轮廓的例子。

光学系统包含激光束分割部件3和重合照射部件6(61、62)。在本例子中，在激光束分割部件3中利用波导4，把激光束1分割为所需数量的分割束16a~16e，通过重合照射部件6把这些分割束在照射面90上成像为直线状轮廓的照射光束19。

在本实施例中，激光束分割部件3包含用于使来自激光振荡器的激光束1入射到波导4内的光学系统，包含用于产生平行光束的扩束透镜31、y方向准直透镜32和x方向准直透镜33，下面还包含在y方向聚光、并使其入射到波导4内的柱面透镜的聚光透镜34。

波导4中彼此相对的平行主表面具有反射面41、42，反射面41、42在该图中与y方向垂直。激光束1贯穿两个反射面间的入射面43和出射面44与激光束的光轴正交。入射的激光束1通过反射面之间被分割成：从出射端射出的分割束成分、在反射面41和42的任意一个反射一次(m=1)的两个分割束(m=+1，m=-1)成分、在两个反射面反射两次(m=2)的分割束(m=+2，m=-2)成分、还有分别反射三次乃至三次以上一对分割束从出射端射出的各成分。

来自波导4的分割束通过重合照射部件6重合投射到照射面90上。重合照射部件6由在y方向把分割束复制到照射面上的y方向复

制透镜 61（柱面透镜）和在 x 方向聚光的聚光透镜 62（柱面透镜）构成. y 方向的复制透镜 61 通过 x 方向聚光透镜 62，在照射面 90 上把光束在 y 方向延伸规定的长度，x 方向聚光透镜 62 使光束在 x 方向汇聚为线状，据此，在照射面上取得了直线状轮廓的照射光束 19.

更具体而言，图 2 表示了使用激光束分割部件的波导、分割从激光振荡器（未图示）射出的激光光束的形态，但是来自激光振荡器的激光束通过柱面透镜的聚光透镜 34，经过焦点 F_0 入射到波导 4 内. 在波导 4 内，入射光束的一部分具有没有在反射面反射就透过的分割束（反射次数=0），在彼此相对的反射面 41 或 42 只反射了一次的分割束在 y 方向有 2 种（m= ±1），在反射面 41 和 42 反射两次的分割束也同样在 y 方向有 2 种（m= ±2），各分割束从出射面 44 射出. 在垂直于光轴、并且包含焦点 F_0 的面上，有从出射面 44 射出的各分割束的虚像焦点 F_{+1}、F_{-1}、F_{+2}、F_{-2}，能观察到各分割束从这些虚像焦点 F_{+1} · · · ·经过出射面 44 的开口被射出.

在图 2 中，如果假定通过没有波导时的聚光透镜 34，通过焦点而扩展的激光束投影到出射面 44 所在的面的光束的轮廓为圆，该投影的激光束 14 能分解为与多个分割束分别分类对应的成分. 激光束 1 的截面的各成分在截面上，如果在 y 方向按 m=-2、-1、0、+1、+2 的顺序分割，则需要注意从波导 4 的出射面 44 射出的成分即分割束在 y 方向为反射次数=+2、+1、0、-1、-2 的顺序的排列.

在图 2 中，只表示了从波导 4 的出射面 44 射出的 m=0、+1、+2 的成分的分割束的配置，m=+1 和 m=+2 的分割束对于反射面的中间面向彼此相反的方向射出. 而 m=-1、-2 的分割束对于 m=+1、+2 的反射面的中心面位于对称方向，但是在图中省略了.

图 3A 是把激光束从焦点 F_0 在波导 4 不反射，投影到波导 4 的出射面 44 的对应平面上的激光束 14 的分割束的分割宽度图示化的图. 它是遵循高斯分布的圆形轮廓的激光束 14 由波导分割为 7 束的例子.

在波导 4 中，彼此相邻的分割束在其出射面 44 上反复重叠. 因此，基于激光束 1 的分割而彼此相邻的成分的边界部位在图 3B 中，与波导

的出射面的分割束的反复部分一致。例如，在图 3A 中，m=+1 的成分的边界部 III 和与它挨着的 m=0 的边界部 iii 在波导的出射面 44 中反复重叠（如图 3B 所示）。

如果这样的反复的分割束通过 y 方向复制透镜 61 和 x 方向聚光透镜 62，重合投影到照射面 90 上，则在照射面上的照射光束中发生干涉，强度形成了波状分布。

图 4 表示了来自分割束的两个成分，例如反射次数 m=+1 和 m=0 的两个成分通过 y 方向复制透镜 61 和 x 方向聚光透镜 62 等，重合照射到照射面 90 上时的照射面 90 上的照射光束 19 的强度分布图的例子。但是在原来的激光束上彼此相邻的分割束边界部 iii 和 III 严重地彼此干涉，而同样在原来的激光束上彼此远离的分割束边界部 IV 和 ii 表现了干涉引起的强度分布的变动小。在图 4 中，在横轴上取分割宽度 d，在纵轴上取相对的光束强度。只是，图 4 是把激光束的强度分布近似为高斯分布，分割宽度 d 与空间的干涉距离 s 相等时的情形。

照射面上的重合引起的干涉的程度依赖于分割宽度 d 和该位置处的激光束空间的干涉距离 s 的比。这里，把空间的干涉距离 s 定义为在激光束的光束截面的强度分布保持高斯分布时，如图 5 所示的那样，规定光束直径 D 是强度变为光轴强度 $1/e^2$（这里，e 是自然对数的底）时的圆（$1/e^2$ 圆）的直径 D，是把单一的激光束分支为两个时的双方的 $1/e^2$ 圆的中心间的距离，这时从在照射面上使它们光轴为公共的后使其干扰的状态，把光轴彼此错开，在重叠的照射区域中，干涉条纹的可见度降低到 1/e。这里，可见度是把干涉后的强度分布的最高强度和最低强度的差除以最高强度和最低强度的和而得到的值，是表示干涉的程度的尺度。

当激光束的分割宽度 d 为 d=s/2 时，彼此相邻的分割束的彼此接近的区域的照射光束的重叠部分中，可见度接近 1，在远离的区域的照射光束的重叠部分中可见度为 1/e。中间的区域中，从 1 向 1/e 渐渐减小。在较佳的实施例中，分割宽度 d 为 d=s/2 以上，这时远离的区域的照射光束的重叠部分中可见度降低到 1/e 以下。

激光束的分割宽度 d 为 $d=s/\sqrt{2}$ 以上时，在远离的区域的照射光束的重叠部分中可见度降低到 $1/e^2$. 在最佳的实施例中，在远离的区域的照射光束的重叠部分中可见度降低到 $1/e^4$ 以下.

使分割宽度 d 为 d=s，如图 2 所示，通过波导 4 把激光束分割为 7 束，图 6 表示出在照射面上重合时的强度分布，表现了得到相当改善的强度分布. 在该图中，产生的干涉条纹的周期 T 由 $T=\lambda/\sin\Delta\theta$ 决定. 这里，λ 是波长，Δθ 是产生干涉的两个分割束在照射面 19 上的入射角的差.

实施例 2

本实施例中，利用柱面透镜阵列作为另一种光束分割部件. 本例如图 8A 和 8B 所示，激光束均匀照射的光学系统包含用于使来自激光振荡器的激光束 1 入射到柱面透镜阵列 5 的光学系统，包含用于产生平行光束的扩束透镜 31、y 方向准直透镜 32 和 x 方向准直透镜 33，来自准直透镜 33 的平行光束入射到柱面透镜阵列 5.

在柱面透镜阵列 5 中，柱面透镜指的是在图中 x 方向为柱状、向着光轴把截面凸透镜层叠在 y 方向的透镜，但是图例由 5 级这样的微小的柱面透镜 5a~5e 构成，据此，形成了五个分割束.

来自分割光束用的柱面透镜阵列 5 的向 y 方向的分割束 15a~15e 入射到配置在前方的另外的复制用柱面透镜阵列 51，来自复制用柱面透镜阵列 51 的分割束通过在 x 方向聚光的聚光透镜 62（柱面透镜）投射到照射面 90 上，形成具有在 y 方向均匀、在 x 方向汇聚得很细的线状轮廓的照射光束 19. 物镜 63 配置在复制用柱面透镜阵列 51 和聚光透镜 62 之间.

图 9A 和 9B 表示了柱面透镜阵列 5 的激光束的分割形态. 与前面所述的由波导进行的分割不同，用各微小柱面透镜分割的光束在照射面上重合时，没有返回，只是被重叠，因此，即使两个相邻的分割束通过复制用柱面透镜阵列 51 和 x 方向聚光透镜 62 在照射面上重合，合成后的强度分布在 y 方向的干涉中也没有差异.

图 10 表示分割宽度 d 与上述的空间的干涉距离 s 相等时、彼此相

邻的两个分割束在照射面上的重合的强度分布在 y 方向一定，它的可见度是一定的，为 1/e.

图 11 表示关于通过所述分割用的柱面透镜阵列 5 分割为 7 束的分割束，分割宽度 d 为 d=s，在照射面上重合时的强度分布，但是 y 方向，表现了相当好的分布.

实施例 3

本发明的实施例的光学系统中，所述均匀化部件包含：通过所述波导形成的分割束中彼此相邻的分割束的一方相对于另一方，延迟比该激光束的时间的干涉距离还长的光学延迟部件. 为了防止激光束的彼此相邻的区域发出的两条分割束之间发生干涉，光学延迟部件在彼此相邻的区域的两条分割束之间设置了时间的干涉距离以上的光程差.

本实施例作为光学延迟部件，表示利用了透光性的延迟板的光学系统. 如图 12A 和图 12B 所示，光学系统使用：利用了波导 4 的激光束分割部件 3、作为重合照射部件 6 的正交的两个柱面透镜（61、62）、作为光学延迟部件的延迟板 7. 本例子中，波导 4 与实施例 1 的波导同样，把激光束 1 分割为所需数量的分割束 16a~16e，通过重合照射部件 6 把这些分割束在照射面 90 上作为直线状轮廓的照射光束 19 而成像.

在图 12B 中，在多个分割束彼此分离的位置，在彼此容易产生干涉的分割束的任意一个中，插入透光性的延迟板 7（即光学玻璃板 2）作为光学延迟部件，在相邻的分割束之间形成光程差. 本例子中，由波导 4 分割的光束由 y 方向复制透镜 61 复制，通过 x 方向聚光透镜 62 在照射面上形成照射光束，但是在 y 方向复制透镜 61 和 x 方向聚光透镜 62 之间，通过 y 方向复制透镜 61 在各光束中形成焦点 f，把作为延迟板 7 的玻璃板插入在相邻的光束的任意一方中的焦点位置 f 或它的前后，设置光程差. 图的例子中，在 5 个分割束中每隔一束中插入作为延迟板 7 的玻璃板，在彼此相邻的延迟板 7、7 之间的空间中，其他的分割束通过. 通过这样排列的延迟板 7，重合在照射面上的照

射光束中，不产生彼此相邻的分割束间的干涉，所以实质上能取得强度分布均匀的轮廓。

玻璃板的光程差Δa由玻璃板的厚度a、玻璃的折射率n_1、空气的折射率n_0（可是，通常$n_0=1$）给出。$\Delta a=(n_1-n_0)/n_1$。

玻璃板的光程差Δa设定为时间的干涉距离ΔL以上。即Δa□ΔL。而激光束的时间的干涉距离由$\Delta L=c\Delta t\fallingdotseq\lambda^2/\Delta\lambda$提供。这里，c是光速，Δt是可干涉时间，Δλ是激光具有的波长宽度（频谱宽度），激光的波长宽度越窄，干涉距离越长。

举例来说，在Nd:YAG激光器中，关于中心波长$\lambda=1.06\mu m$的光束，频谱宽度$\Delta\lambda=0.12\sim0.30mm$，所以时间的干涉距离$\Delta L=3.8\sim9.4mm$。

在图7中表示了从激光束的彼此相邻的区域分割出的两个分割束在照射面上的可见度和分割束间设置的光程差的距离（即光程差Δa）的关系。当光程差为时间的干涉距离ΔL时，可见度下降到1/e，通过使来自分割束间的光程差进一步增大，可见度进一步减小。

从这些关系求出彼此相邻的分割束间提供时间的干涉距离ΔL以上的光程差的玻璃厚度a。延迟板的厚度希望设定为通过延迟板设置时间的干涉距离ΔL的2倍以上的光程差，更希望为4倍以上。例如，光源是所述的Nd:YAG激光器，当对光学延迟部件的延迟板7使用了石英（折射率$n_1=1.46$）时，对于时间的干涉距离ΔL为3.8~9.4mm，石英玻璃厚度a为12~30mm。

图13是本实施例3的变形例，表示从x方向观察的光学系统的配置。除了光学延迟部件7的配置的不同，基本上是与图12A和图13B的光学系统相同的激光束均匀照射的光学系统，但是本例子遮断了在所述的波导的反射面间不反射而通过的分割束。

即，来自所述图2、图3A和图3B所示的波导4的反射次数m=0时的直线前进的光束由配置在y方向复制透镜后的焦点位置f的遮蔽体79遮断。由于m=0的直线前进的光束被遮蔽体79阻挡，不到达照射面，所以它对干涉没贡献。因此，作为光学延迟部件7，只插入对称配置的分割束组（m=+1、-2）或（m=-1、+2）的任意一方，在另一

方的光束组不配置光学延迟部件 7，据此，减轻照射面上的分割束间的干涉，并且光学延迟部件 7 能利用使一方的分割束组（m=+1、-2）统一透射的单一延迟板 71，例如一块玻璃板或玻璃棒，具有能简化光学系统的优点.

其他变形例的光学系统包含波导 4 和光学延迟部件 7，只是提供的由波导构成的激光束分割部件不含有在波导 4 内不反射而直线前进的分割束，使所有的分割束至少反射一次，并且防止两个以上的反射分割束反射相同的次数. 如图 14 所示，这样的激光束分割部件能采用激光束分割部件的入射光学系统的光轴相对于波导的中心轴以给定的角度斜交配置的构造.

如图 15、图 16A 和图 16B 所示，设定为入射到波导 4 内的柱面透镜的聚光透镜 34 的光束的周边成分①入射到波导 4 的入射面，在反射面反射一次，从出射面出射；来自聚光透镜 34 的其他光束成分②、③、④分别被反射两次、三次、四次，其他成分被更多次反射，从出射面射出. 被射出、分割的光束在图 15 的出射面一侧，用反射次数 m 的数字 1~8 表示.

在图 16A 和图 16B 中，描述了出射面 44 上的平面中的光束截面的分割束的配置和出射面中分割束的重合. 反射次数的顺序表示了激光束截面中的分割束的配置的顺序. 因此，反射次数的顺序差 1 的分割束彼此在照射面上容易干涉，所以在顺序差 1 的分割束的任意一方中配置延迟板 7 作为空间的迟部件. 如图 14 所示，该延迟板的配置在 y 方向复制透镜的焦点 f 位置，反射偶数次数（例如，m=2、4、6）的分割束群对于奇数次数（m=1、2、3）的分割束群，偏向一方，所以通过在反射偶数次数 m=2、4、6 的分割束全体中插入单一的延迟板 72，能简单地防止相邻的分割束彼此的干涉.

在图 16A 和图 16B 中，如上述的实施例所述，分割束的宽度 d 被设定为大于、等于空间的干涉距离 s 的 1/2，希望在 $1/\sqrt{2}$ 以上，特别是大于、等于 1 个 s.

图 17 表示不形成在波导 4 内直线前进的分割束的其他变形例. 本

例子中，使波导 4 的光轴 40 与聚光透镜 34 的光轴 30 一致，但是通过使波导 4 的入射面 43 不与光轴正交，以适当的角度斜交，使斜交的入射面 43 上的入射光束 13 折射，也能得到没有 0 次反射，而有 1 次、2 次、3 次等的反射的分割束。在本例子中，通过在 y 方向复制透镜的焦点 f 位置，在偶数次反射（例如 m=2、4、6）的分割束或奇数次反射（例如 m=1、3、5）的分割束中集中插入一个延迟板 71，就能设置彼此相邻的分割束间的光程差。

实施例 4

本实施例表示应用所述实施例 2 的柱面透镜阵列作为分割部件和把所述延迟板作为延迟通过该柱面透镜阵列分离的分割束的光学延迟部件、防止干涉的例子。

图 18A 和图 18B 中，在从分割用的柱面透镜阵列 5 在 y 方向上分割出的分割束 15a~15e 中插入了延迟板 7 作为光学延迟部件。本例子各延迟板 7 被插入隔一个分割束的分割束 15a、15c、15d 中，在其他的分割束 15b、15d 中不插入。据此，限制了彼此相邻的分割束间（例如，分割束 15a 和 15b 之间，或分割束 15b 和 15c）的照射面 90 上的干涉，能使由重合的照射光束产生的干涉的强度分布均匀化。

图 19 是图 18A 和 18B 所示的激光束均匀照射的光学系统的变形例，但是分割用的柱面透镜阵列 5 的分割束和它的前方的复制用柱面透镜阵列 51 的前方的焦点位置处分别配置一对延迟板 73 和 74。在本例子中，因为在复制用柱面透镜阵列 51 的前后配置了两个延迟板 73 和 74，所以能使延迟板的被复制面与复制面为共轭关系，据此，具有能使照射面上的衍射的影响最小的优点。

图 20 是图 18B 所示的激光束均匀照射的光学系统的变形例，只是，把插入了延迟板 7 的分割束的复制用柱面透镜阵列 51 的微小透镜 512 和不插入延迟板 7 的分割束的复制用柱面透镜阵列 51 的微小透镜 511 制作为具有不同的焦点距离，使它们在照射面上的成像变为一样。通过在由分割用柱面透镜阵列 5 于 y 方向上排列、分割得到的分割束的每隔一个分割束中插入调整光程长用的延迟板 7，对于不插入延迟板

的分割束，产生了焦点位置 f 的偏移，但是用复制用柱面透镜阵列 51 的各微小透镜的焦点距离来补偿焦点 f 的位置偏移，据此，能使照射面上成像的各分割束的强度分布均匀化.

实施例 5

在本实施例中，应用旋光部件作为均匀化部件，防止彼此相邻的分割束在照射面上的干涉，实现均匀化. 本光学系统表示包含作为激光束分割部件的波导、作为重合照射部件的柱面透镜阵列和作为均匀化部件的旋光部件的激光束均匀照射的光学系统. 本光学系统形成在照射面上，在 y 方向以均匀的分布扩展，在 x 方向为线状汇聚的直线状的照射轮廓. 激光束分割部件 3 利用波导 4，把激光束分割为所希望数量的分割束，通过重合照射部件把分割束在照射面上成像为直线状的轮廓.

本实施例的光学系统中，所述的均匀化部件包含：使由所述的波导形成的分割束中彼此相邻的相邻分割束中的任意一方相对于另一方，偏振面的角度实质上正交的旋光部件. 该旋光部件使来自彼此相邻的区域的分割束的偏振面彼此正交，防止分割束彼此的干涉.

旋光部件进行旋光，使偏振面的相对角度实质上正交，从而使彼此相邻的两个分割束达到彼此实质上不发生干涉的程度，希望利用由石英构成的半波长板.

在图 21A 和 21B 中，在波导 4 的前方的 y 方向复制透镜 61（柱面透镜）的前方形成焦点 f，把半波长板 8 作为旋光部件配置在该焦点位置. 在本例子中，来自波导 4 的五个分割束中，只在反射次数 m=0、m=+2 和 m=-2 的三个分割束中插入半波长板 7，在 m=+1 和 m=-1 的其他反射次数的分割束中不插入. 该结构在排列在 y 方向的分割束的每隔一个中插入半波长板. 据此，参照图 2 和图 3A，只在彼此相邻的两个分割束中的任意一方中插入半波长板 8，使其偏振角相对于另一方的分割束实质上正交. 据此，在彼此相邻的任意组合的两个分割束中，即使在照射面 90 上重合，也不会发生干涉. 因此，与所述分割宽度的限制一起，通过实质上偏振面不同的光束的重合，改善了照射光

束的均匀性。

本实施例作为均匀化部件，使排列在 y 方向的分割束每隔一个中插入半波长板 8，所以有必要在半波长板 8、8 之间设置间隙，使其他分割束透过，该半波长板的配置和构造有些复杂。

为了解决这个问题，在图 22 所示的构造中，特别是通过配置在 y 方向复制透镜 61 的出射一侧的焦点位置 f 处的遮蔽体 89 遮断反射次数 m=0 的直线前进的光束。m=0 的直线前进的光束不到达照射面，所以它对干涉没贡献。因此，作为旋光部件，把一块半波长板 8 插入对于直线前进的光束（m=0）对称配置的分割束群（m=+1、-2）或（m=-1、+2）的任意一方中，另一方的分割束组不配置旋光部件。据此，减轻了照射面 90 上的分割束 19 彼此间的干涉，并且旋光部件 8 能利用使一方的分割束组（m=+1、-2）一起透过的一块半波长板 82，具有能简化光学系统的优点。

遮蔽体 89 能利用吸收或使激光束反射的固体，例如石墨、陶瓷、金属等，也能把遮蔽体 89 与所述单一的旋光部件 82 组装为一体，配置在 y 方向复制透镜 61 的焦点位置 f。

图 22 的所述变形例通过遮蔽体 89 遮断了中心的分割束 m=0，但是因为遮断的中心的光束 m=1 具有相当大的能量，所以不利用它会导致效率下降，在这一点上是不经济的。

因此，下一个变形例中，入射激光的光轴相对于波导与其反射面 41、42 间的中心轴斜交，如所述实施例 3 的图 14~图 16 已经表示的那样，不生成在反射面 41、42 间不反射而通过的分割束。这时，用反射次数 m 划分的分割束的对称性被破坏，如图 23 所示，波导的光束分割被分离为从一次反射的分割束（m=1）到数次反射（在本例子中，到 6 次（m=6））的分割束，防止两个以上的反射分割束反射相同的次数。并且从图 23 可知，奇数次反射 m=1、3、5 和偶数次反射 m=2、4、6 的分割束在焦点位置 f 集中为一组，所以不用放弃利用图 22 所示的无反射的分割束（m=0），使用单一的旋光部件 8 就能简单配置奇数次反射 m=1、3、5 或偶数次反射 m=2、4、6 的分割束，如图 23 所

示，通过只在反射是偶数次数的分割束组中插入单一的旋光部件 82，就能使彼此相邻的分割束组的偏振面实质上正交，具有能简单地实现防止彼此干涉的优点。

作为所述的图 23 的其他变形例，图 24 所示的光学系统由实心的透光体构成波导 4，形成该波导 4 的入射面 43，使它与波导 4 的中心轴不正交，而是适当地斜交，使来自所述光源一侧的所述聚光透镜 34 的激光束 12 入射到斜交入射面 43 上，并折射。结果，能使入射的光束在反射面 41、42 之间至少反射一次，与图 23 同样，不生成不反射而通过的分割束（m＝0），能设定反射次数一次一次增加的分割束，这时用单一的半波长板划分为只有偶数次反射的分割束或奇数次反射的分割束，能统一使这些划分的分割束群偏振。这时，因为与波导的中心轴共轴配置聚光透镜 34 的光轴，所以光学系统的设计组装是容易的，并且能实现与图 23 同样的效果。

在所述实施例中，旋光部件在所述例子中，在相邻的分割束中插入半波长板，防止彼此干涉。但是半波长板同时实质上延长了该分割束的光程长，所以在插入了半波长板的分割束和未插入半波长板的分割束之间产生光程长的差。这样，如果两种分割束的光程长不同，则照射面上的照射光束的成像位置彼此偏移，照射面上的光束强度轮廓变得不鲜明，特别是取线状轮廓时，宽度方向强度分布扩展。下面，表示插入为此的光程长补偿板、防止产生光程差的例子。

图 25 使用图 21B 所示的波导分割光束，在 y 方向复制透镜 61 的焦点位置 f，如上所述，在每隔一个分割束中插入半波长板 8、8。本例子对不插入半波长板的另一方的分割束插入延长光程长的延迟板 83 作为光程长补偿部件。本例子使用光学玻璃板作为延迟板 83，其厚度设定为使产生与由半波长板产生的光程长相同。在照射面上，不产生这些分割束间彼此的光程差，能确保照射轮廓的鲜明度。

图 26 是在图 23 的例子中应用了延迟板 83 的例子，在 y 方向复制透镜 61 的焦点位置 f，在偶数次反射的分割束（m=2、4、6）组中，如上所述，统一插入单一的半波长板 82，在另一方的奇数次反射的分

割束（m=1、3、5）组中不插入单一的延迟板 83，消除了光束群之间的光程差。本例子特别的优点是能使单一的半波长板 82 和单一的延迟板 83 一体化，简单地配置在所述焦点 f 的位置。

实施例 6

本实施例表示应用旋光部件作为均匀化部件、应用柱面透镜阵列作为激光束分割部件的激光束均匀照射的光学系统的例子。

在图 27 中，图示出用于使来自激光振荡器（未图示）的激光束 1 入射到柱面透镜阵列 5 中的光学系统，该光学系统包含用于产生平行光束的扩束透镜 31、y 方向准直透镜 32 和 x 方向准直透镜 33，来自准直透镜 33 的平行光束入射到柱面透镜阵列 5。柱面透镜阵列 5 指的是在图中 x 方向为柱状、向着光轴把截面凸透镜层叠在 y 方向的透镜，但是由 5 级微小的柱面透镜 5a~5e 构成，据此，形成了五个分割束 15a~15e。

来自分割用的柱面透镜阵列 5 的在 y 方向上的分割束入射到配置在它前方的另外的复制用柱面透镜阵列 51，来自制用柱面透镜阵列 51 的分割束通过在 x 方向聚光的聚光透镜 62（柱面透镜）投射到照射面 90 上，形成具有在 y 方向均匀、在 x 方向汇聚得很细的线状轮廓的照射光束 19。物镜 63 配置在复制用柱面透镜阵列 51 和聚光透镜 62 之间。

半波长板 8 作为旋光部件被插入从分割用的柱面透镜阵列 5 在 y 方向分割的分割束 15a~15e 中，但是半波长板 7 被插入每隔一个的分割束 15a、15c、15d 中，在其他的分割束 15b、15d 中不插入。据此，彼此相邻的分割束间（例如，分割束 15a 和 15b 之间，分割束 15b 和 15c 或其他相邻的分割束间），偏振角度实质上正交，抑制了在照射面 90 上的干涉，能使重合的照射光束 19 的干涉产生的强度分布均匀化。

别的变形例表示出了半波长板还包括光程长补偿部件的例子，图 28 是在图 27A 和图 27B 所示的光学系统中，在不插入旋光部件的相应的另一方的分割束（在本例子中，15b、15d）中插入延迟板 83 的玻璃

体作为光程长补偿部件的例子．如上所述，所述一方的分割束被配置了半波长板 8 作为旋光部件，但是半波长板 8 的插入延长了该分割束的光程长．如果两种分割束的光程长不同，照射面上的成像位置就彼此偏移，轮廓变得不鲜明．为了进行修正，在另一方的分割束中插入延长光程长的延迟板 83 作为补偿光程长的部件．本例子把延迟板 83 的光学玻璃板设定为产生与由半波长板 8 产生的光程长相同的厚度．因为图 27 的配置交替排列半波长板 8 和延迟板 83，所以交替并且一体地连接半波长板 8 和延迟板 83，能形成一体的均匀化部件．

图 29 是在图 27 所示的激光束均匀照射的光学系统的复制用柱面透镜阵列 51 中，把插入了半波长板 7 的分割束的微小透镜 512 和不插入半波长板 7 的分割束的微小透镜 511 制作为具有不同的焦点距离，使它们在照射面 90 上的成像变为一样．通过在由分割用柱面透镜阵列 5 分割、排列在 y 方向的分割束的每隔一个分割束中插入旋转偏振面用的半波长板 8，对于不插入半波长板的分割束，产生了焦点 f 位置的偏移，但是本例子用复制用柱面透镜阵列 51 的各微小透镜的焦点距离补偿焦点位置的偏移，据此，能使照射面上成像的各分割束的强度分布均匀化．

实施例 7

在本实施例中表示的激光束照射的光学系统由分割来自激光光源的激光束的激光束分割部件和在照射面上重合照射分割束的重合照射部件构成，重合照射部件在向照射面上复制各分割束时，各分割束在照射面上彼此错开，即彼此位移，形成照射光束．

本实施例利用波导作激光束分割部件，重合照射部件把来自激光束分割部件的分割束彼此偏移地照射到照射面 90 上，据此，防止照射面上的分割束的彼此干涉，谋求照射光束的均匀化．

在本实施例中，图 30A 和图 30B 中，激光束分割部件包括用于使来自激光振荡器的激光束 1 入射到波导 4 内的光学系统，包含用于产生平行光束的扩束透镜 31、y 方向准直透镜 32 和 x 方向准直透镜 33，还包含在 y 方向上聚光、并使其入射到波导 4 内的柱面透镜的聚光透

镜 34.

波导 4 中，彼此相对的平行主表面具有反射面 41、42，反射面 41、42 在该图中与 y 方向垂直，入射面 43 和出射面 44 与光学轴正交（与 y 方向平行）．由所述的实施例 1 的图 2 和 3 可知，从入射面 43 入射的激光束 1 被分离为在反射面不反射而通过的成分（m=0）和在反射面反射的成分，反射的成分被分离为只反射一次（m=1）的成分、反射两次（m=2）以及反射三次的分割束成分．

来自波导 4 的分割束通过重合照射部件 6 重合投射到照射面 90 上，但是重合照射部件 6 由在 y 方向把分割束复制到照射面上的 y 方向复制透镜 61（柱面透镜）和在 x 方向聚光的聚光透镜 62（柱面透镜）构成．

y 方向的复制透镜 61 通过 x 方向聚光透镜 62，在照射面 90 上，在 y 方向延伸规定的长度，x 方向聚光透镜 62 使光束在 x 方向汇聚为线状，据此，在照射面上取得了直线状轮廓的照射光束 19.

在本实施例中，如图 30B 所示，作为重合照射部件，利用配置在波导 4 的前方的复制透镜 61 的像差，在照射面 90 上，使各分割束 16a~16s 彼此在 y 方向稍微错开照射，据此，如图 30C 所示意地表示的那样，使照射面 90 上合成的照射光束 19 的 y 方向的两端部的重合错开，使它的强度分布为阶梯状，减轻了大的干涉，在均匀的照射范围中，能取得干扰少的强度均匀的照射光束．

图 31A 和图 31B 的例子如实施例 3 的图 14 所示，由透明固体形成波导 4，使它的入射面 43 与之轴向斜交，使入射的激光束折射，从出射面射出由反射面反射一次（m=1）的光束、反射两次（m=2）的光束、反射 3 次（m=3）以至 6 次（m=6）的光束，通过 y 方向聚光透镜 61 和 x 方向聚光透镜 62 把分割束照射在照射面 90 上，但是与图 30A 和图 30B 同样，利用 y 方向聚光透镜 61 的透镜像差，使分割束在图中的照射面 90 上，在 y 方向错开照射，据此，防止了照射面上的分割束彼此的干涉，谋求照射光束的均匀化．

下面的变形例说明的是在使用包括柱面透镜阵列的激光束分割部

件的光学系统中、由重合照射部件在照射面上把各分割的激光束相互偏移地复制、形成照射光束的激光束照射的光学系统。

图 32A 和图 32B 包含放大激光束的扩束透镜 31、y 方向准直透镜 32 和 x 方向准直透镜 33，使平行光束入射到分割用的柱面透镜阵列 5 中。通过柱面透镜阵列 5 分割的光束 15a~15e 通过复制用的柱面透镜阵列 51、y 方向物镜(柱面透镜)63 和 x 方向聚光透镜 62，在照射面上取得在 y 方向延伸的线状轮廓的照射光束 19。而且，调节该物镜 63，使来自激光束分割部件的分割束 16a~16e 彼此错开地照射到照射面 90 上，得到照射光束 19，据此，防止照射面上的分割束的彼此干涉，谋求照射光束在 y 方向的强度均匀化。这时，如图 30C 所示，照射轮廓的 y 方向的两端部表现出阶梯状的强度分布，能在其间得到表现均匀分布的照射光束范围。

如图 33A 和图 33B 所示，本实施例的变形例在分割用柱面透镜阵列 5 和复制用柱面透镜阵列 51 之间配置延迟板 7 作为光学延迟部件，减少激光束截面上彼此相邻的分割束在照射面上的干涉。本例子中，通过形成因物镜 63 产生的重合时的各分割束的偏移而导致干涉的减轻，和因光学延迟产生的各分割束间的干涉的减轻的相乘效果起作用，具有能进一步降低干涉引起的强度分布的变动的优点。

在本实施例中，在光学延迟部件中，在排列的多个分割束中每隔一个分割束配置透光性延迟板 7。通过使相邻的分割束的任意一方的光束透过延迟板 7，在相邻的分割束间形成空间的干涉距离以上的光程差。

下面，说明在均匀化部件中利用使所述分割束的彼此相邻的分割束的一方相对于另一方的偏振方向实质上正交的偏振部件的例子。图 34 所示的例子使激光束从激光源到扩束透镜 31 之间预先通过旋光板 71，在由分割用柱面透镜阵列 5 在 y 方向分割的分割束 15a~15e 中插入半波长板 8 作为旋光部件。但是半波长板 8 被插入每隔一个的分割束 15a、15c、15d 中，在其他的分割束 15b、15d 中不插入。据此，彼此相邻的分割束间（例如，分割束 15a 和 15b 之间，分割束 15b 和 15c

或其他相邻的分割束间），偏振角度实质上正交，抑制了在照射面 90 上的干涉，能使基于重合的照射光束 19 的干涉的强度分布均匀化。在本例子中，在 y 方向被分割的每隔一个光束中插入了半波长板 7，把偏振光通过复制用透镜照射到照射面 90 上，但是，这里通过调节物镜 63，使各分割束在照射面上的 y 方向错开重叠，防止分割束间的干涉。表示错开光束照射在照射面 90 上时的照射光束 19 的强度分布，但是在 y 方向的照射光束 19 的两端部，强度分布降低为阶梯状，但是除了两端部之外的主要部分取得了干涉少的均匀分布。

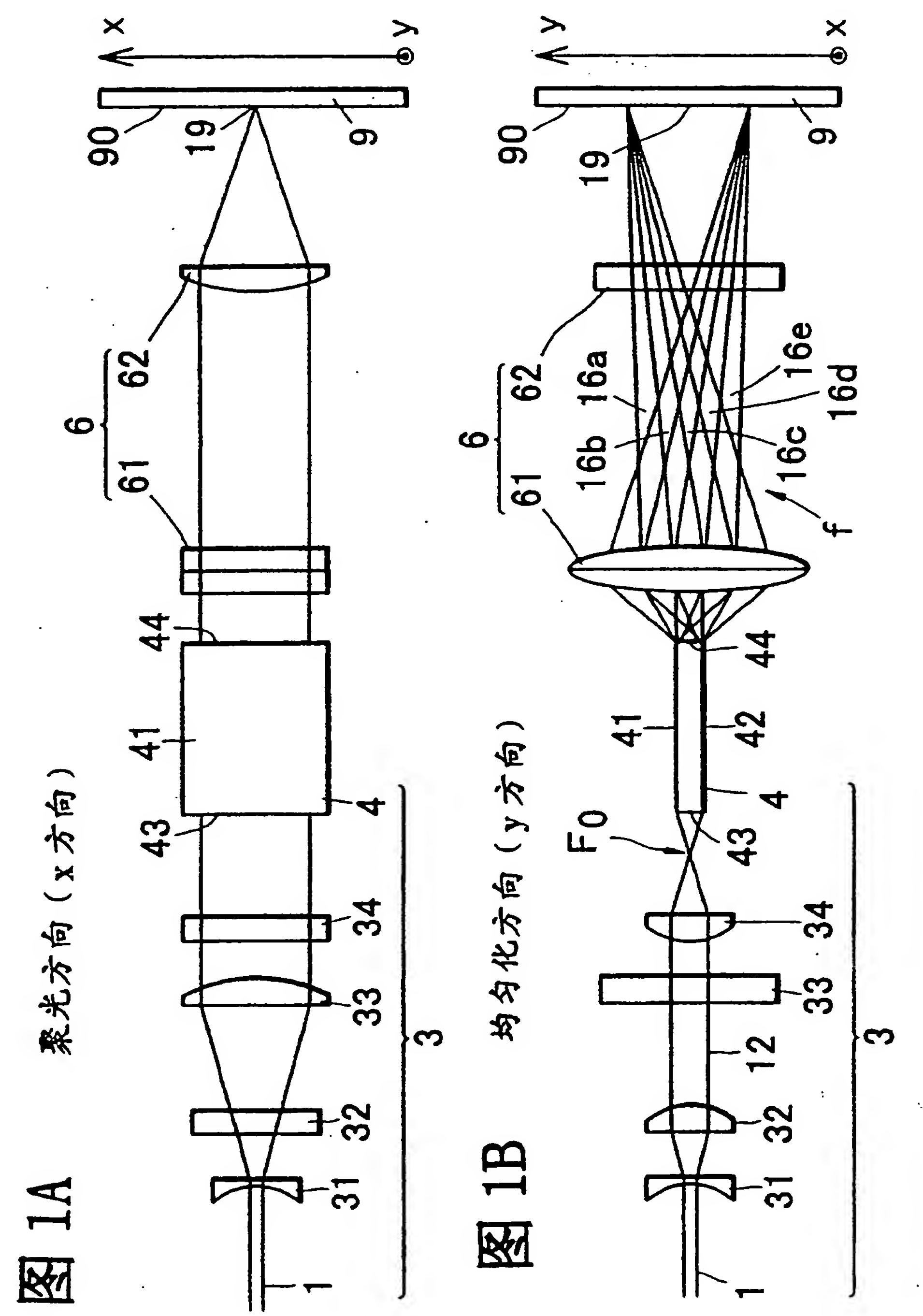

聚光方向（x方向）
x
y
90
19
9
6
61
62
44
41
43
4
34
33
32
31
1
3
均匀化方向（y方向）
y
x
90
19
9
6
61
62
16a
16b
16c
16d
16e
f
44
41
42
4
43
F_0
34
33
12
32
31
1
3

图 1A

图 1B

图2

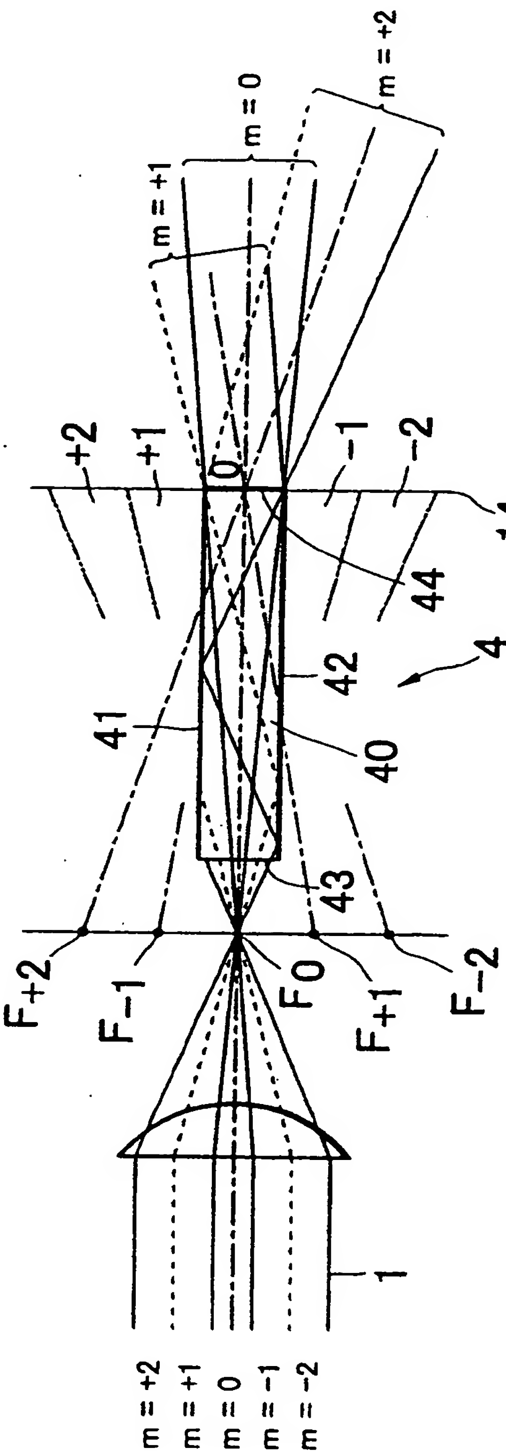


图 3A

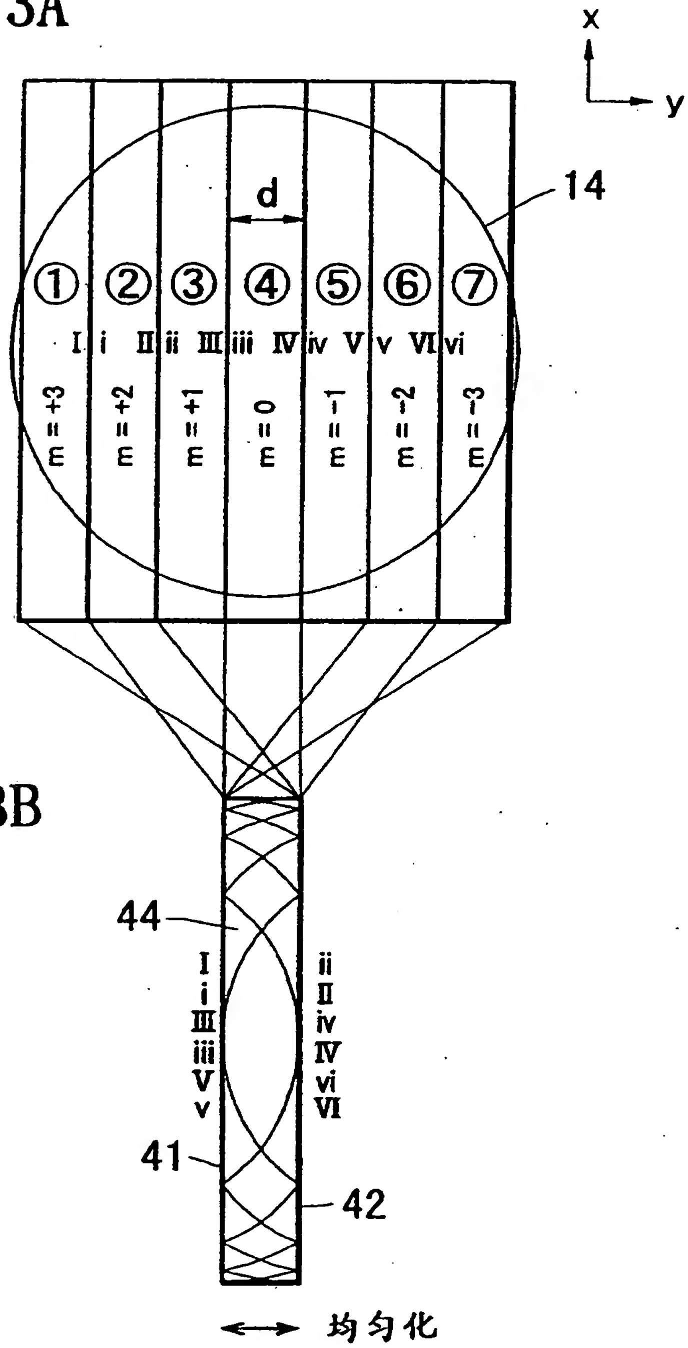
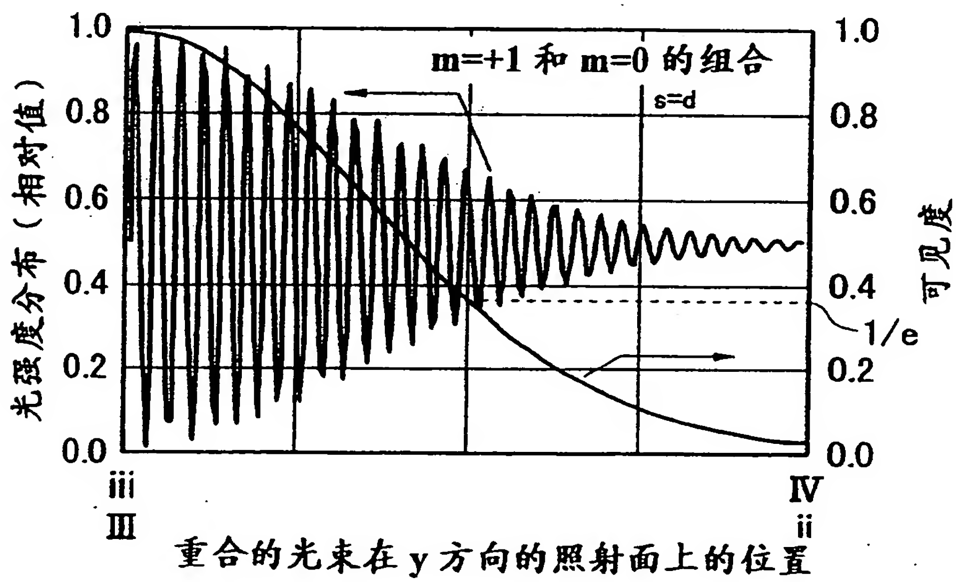

x
y
14
d
①
②
③
④
⑤
⑥
⑦
I i II ii III iii IV iv V v VI vi
m = +3
m = +2
m = +1
m = 0
m = -1
m = -2
m = -3
44
I
i
III
iii
V
v
ii
II
iv
IV
vi
VI
41
42
均匀化

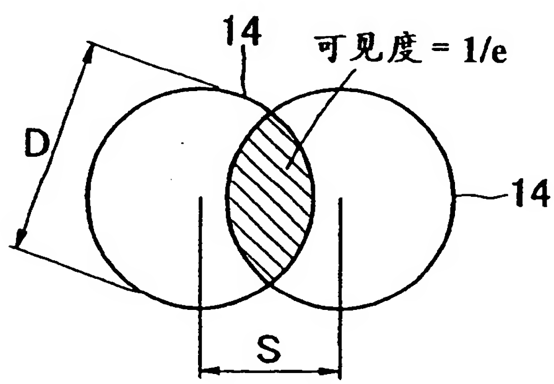
图 3B

图 4



1.0
0.8
0.6
0.4
0.2
0.0
光强度分布（相对值）
m=+1 和 m=0 的组合
s=d
可见度
1/e
iii
III
IV
ii
重合的光束在y方向的照射面上的位置

图 5



14
可见度 = 1/e
D
14
S

图 6

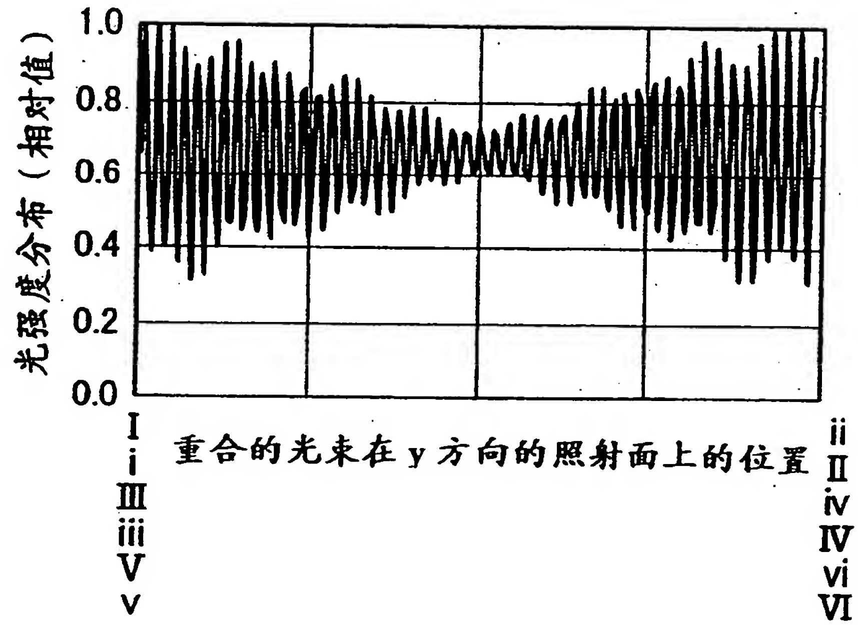

光强度分布（相对值）
1.0
0.8
0.6
0.4
0.2
0.0
I
i
III
iii
V
v
重合的光束在y方向的照射面上的位置
ii
II
iv
IV
vi
VI

图 7

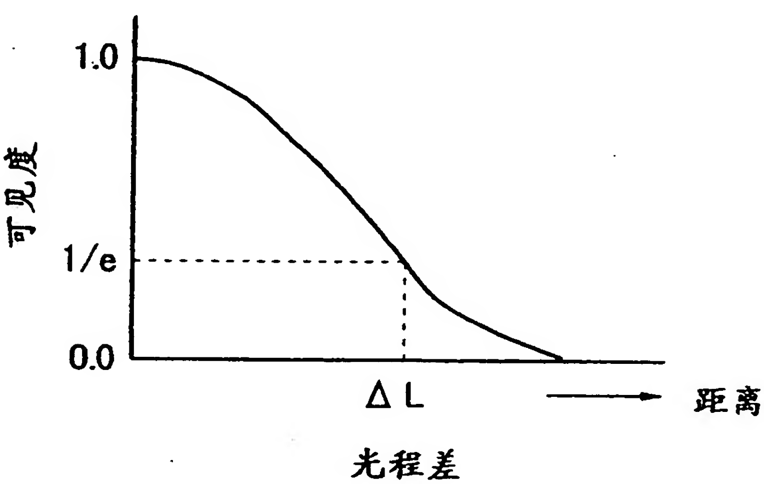

可见度
1.0
1/e
0.0
ΔL
距离
光程差

图 8A

聚光方向（x方向）

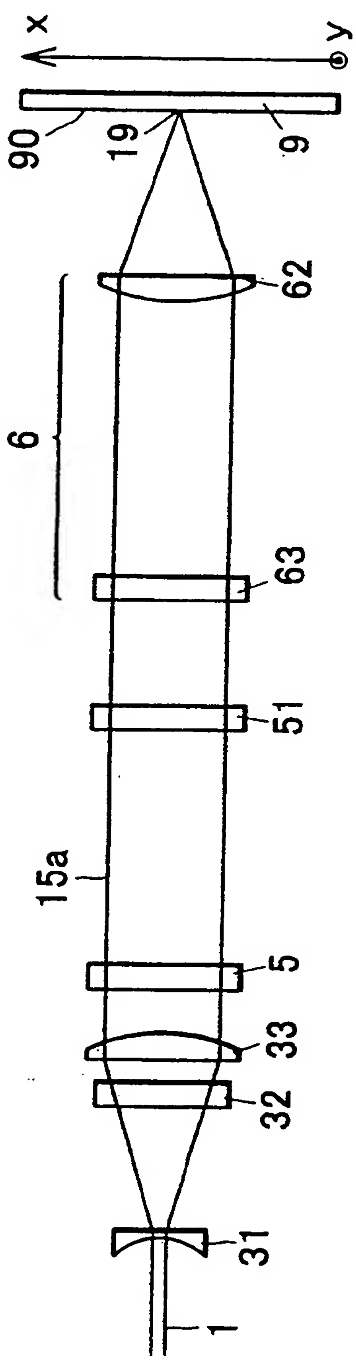


图 8B

均匀化方向（y方向）

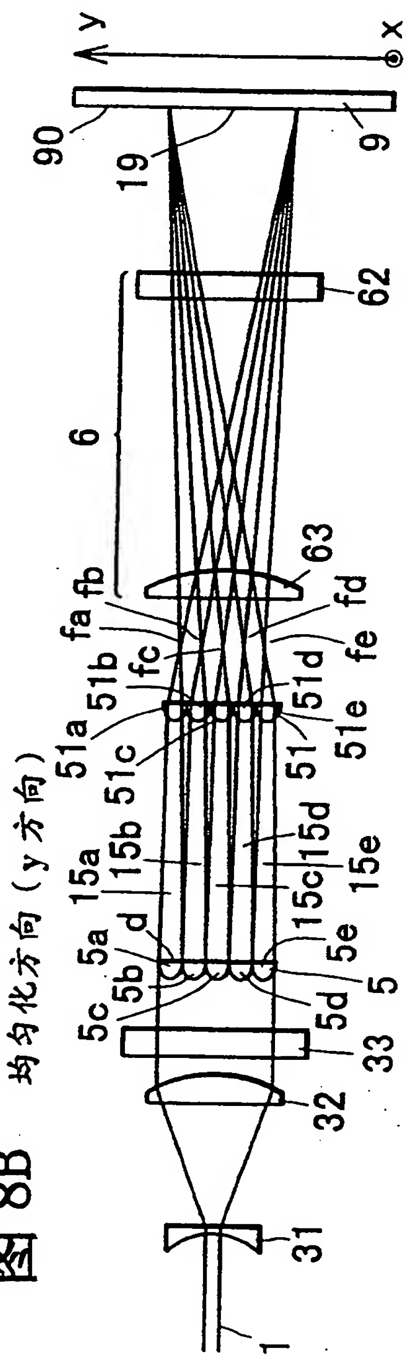


图 9A

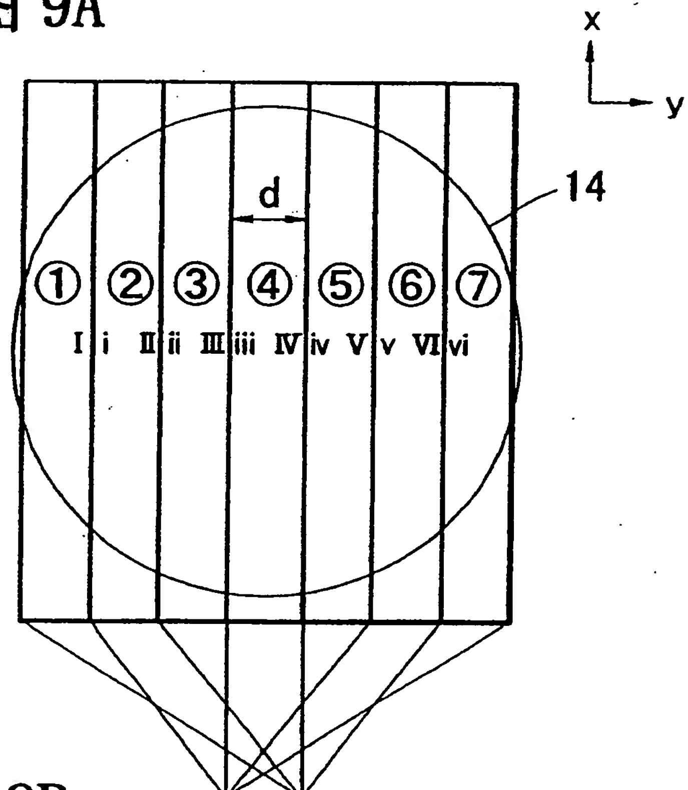

x
y
14
d
① ② ③ ④ ⑤ ⑥ ⑦
I i II ii III iii IV iv V v VI vi

图 9B

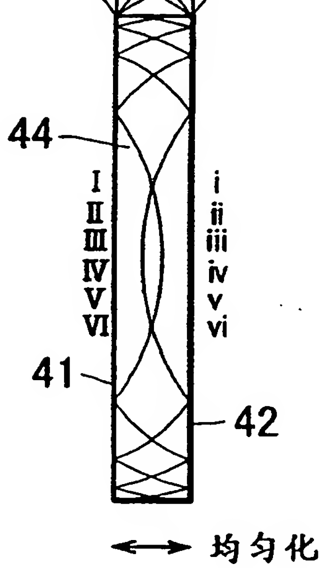

44
I
II
III
IV
V
VI
i
ii
iii
iv
v
vi
41
42
均匀化

图 10

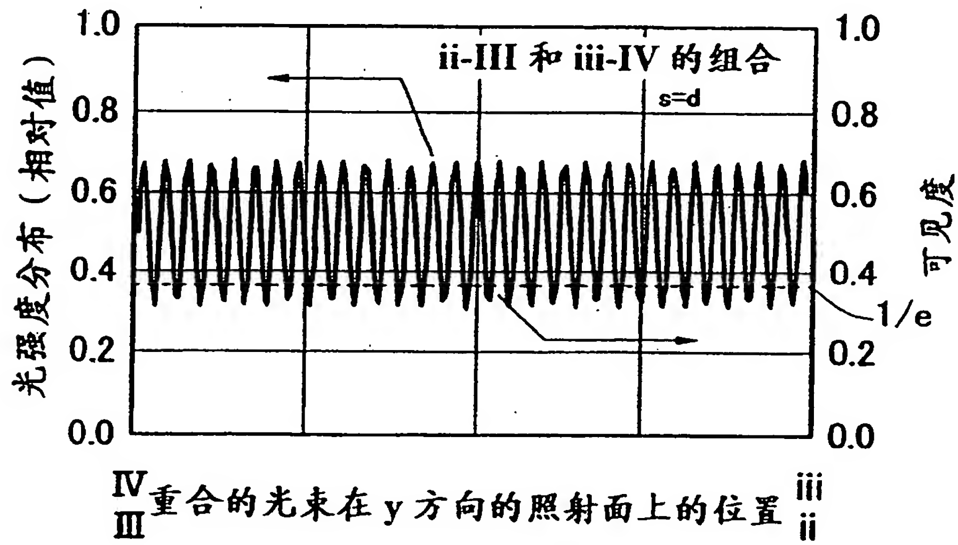

1.0
0.8
0.6
0.4
0.2
0.0
ii-III 和 iii-IV 的组合
s=d
1/e
光强度分布（相对值）
可见度
IV
III
重合的光束在 y 方向的照射面上的位置
iii
ii

图 11

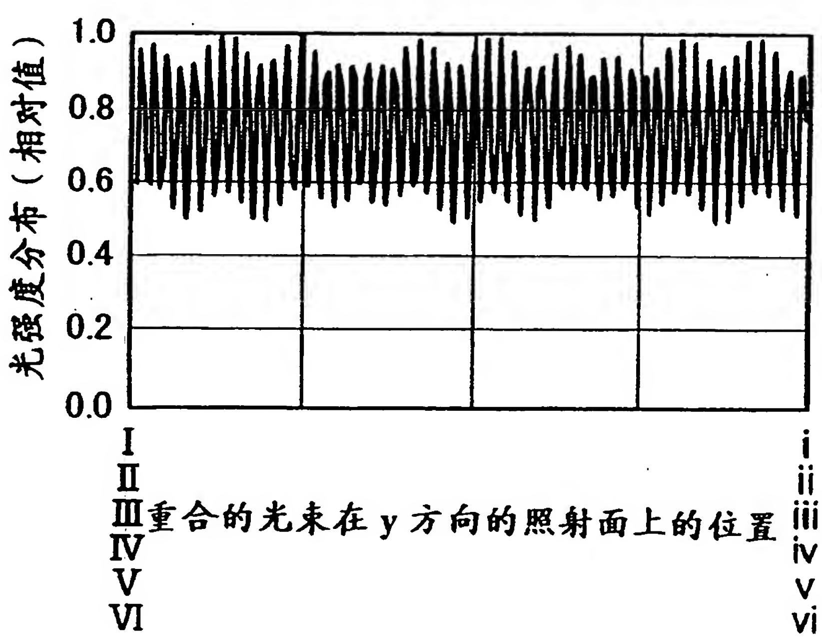

1.0
0.8
0.6
0.4
0.2
0.0
光强度分布（相对值）
I
II
III
IV
V
VI
重合的光束在 y 方向的照射面上的位置
i
ii
iii
iv
v
vi

图12A　聚光方向（x方向）

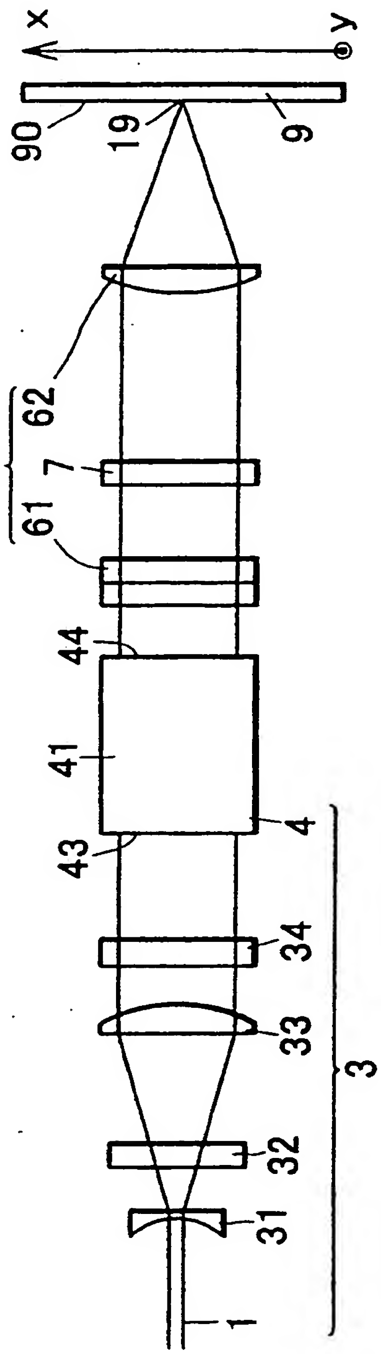


图12B　均匀化方向（y方向）

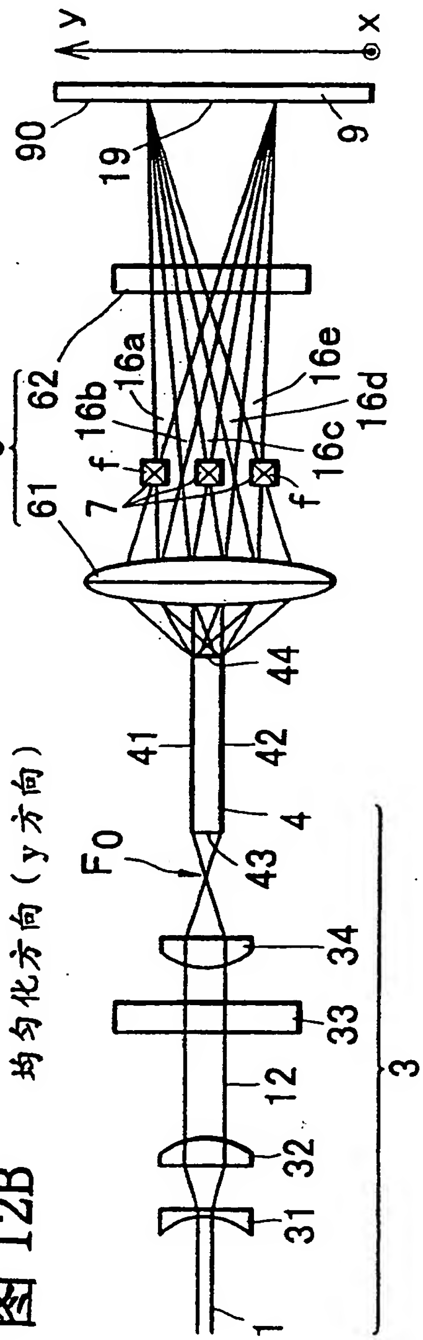


图13

均匀化方向（y方向）

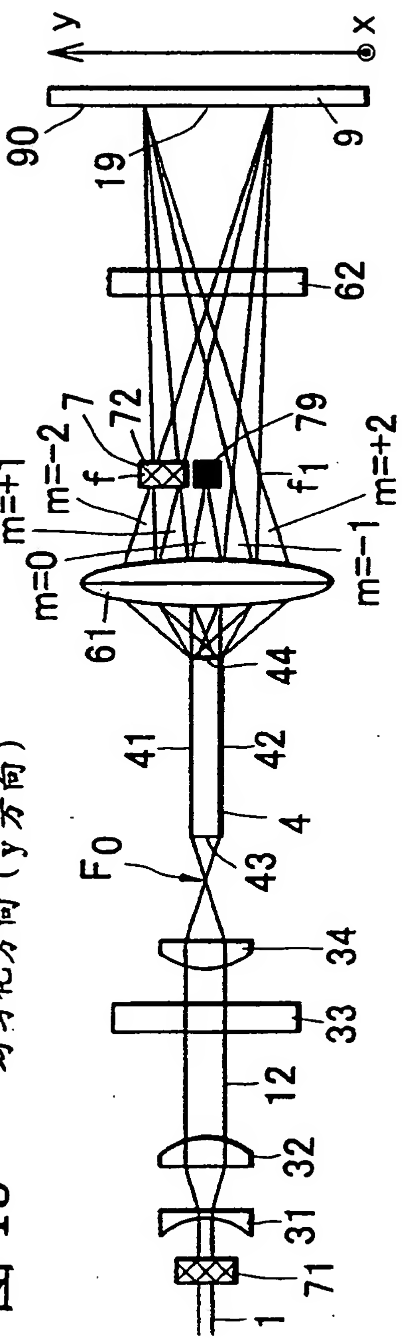
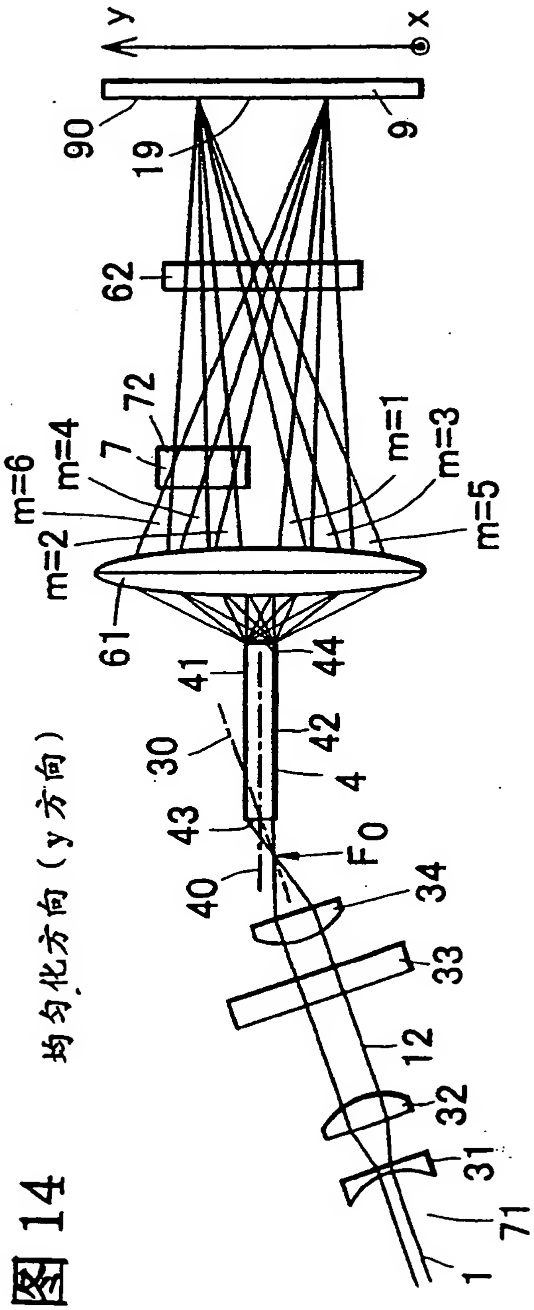


图 14

均匀化方向（y方向）



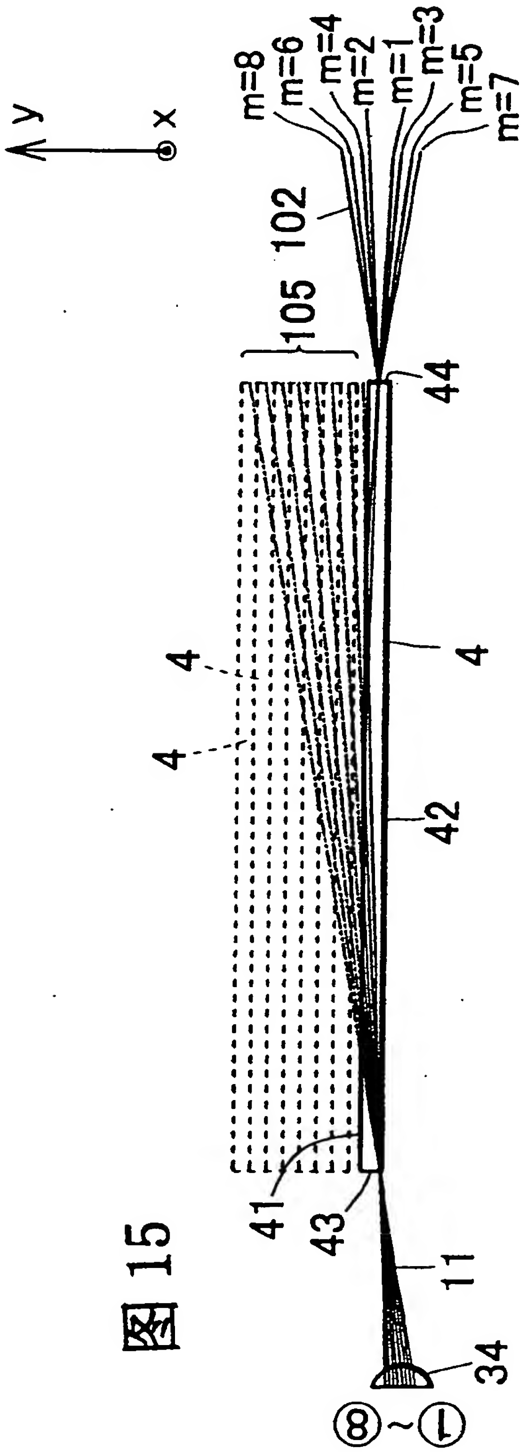


图 15

图 16A

图 16B

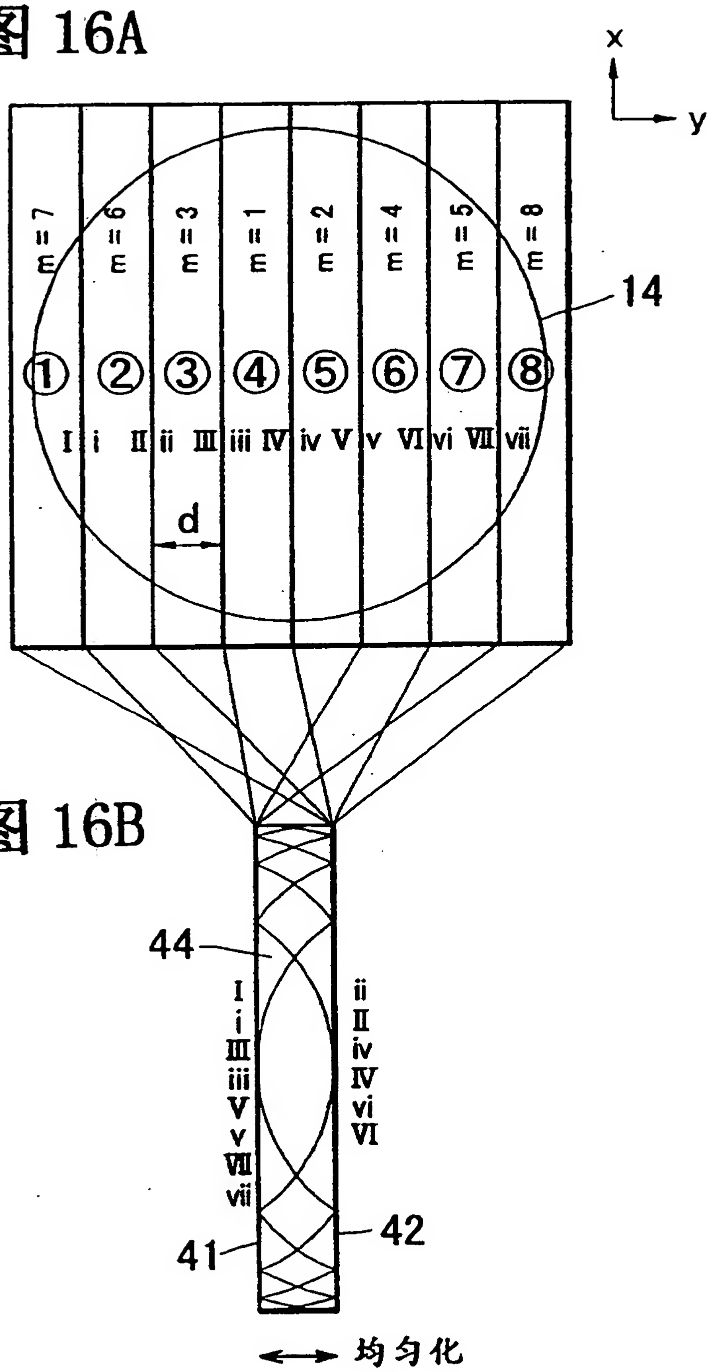
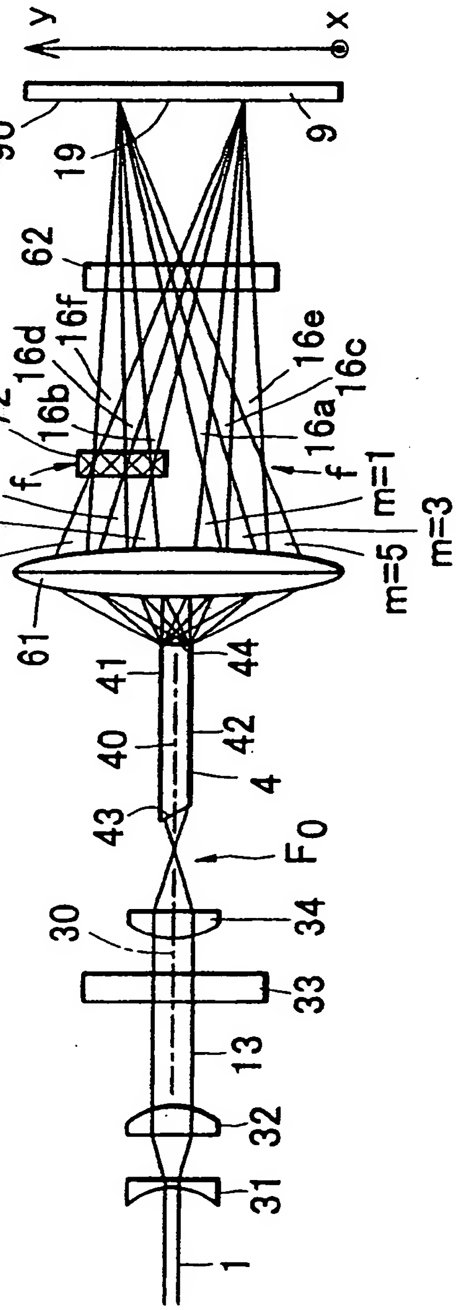

x
y
m=7
m=6
m=3
m=1
m=2
m=4
m=5
m=8
14
①
②
③
④
⑤
⑥
⑦
⑧
I i II ii III iii IV iv V v VI vi VII vii
d
44
I
i
III
iii
V
v
VII
vii
ii
II
iv
IV
vi
VI
41
42
均匀化

图 17

均匀化方向（y方向）



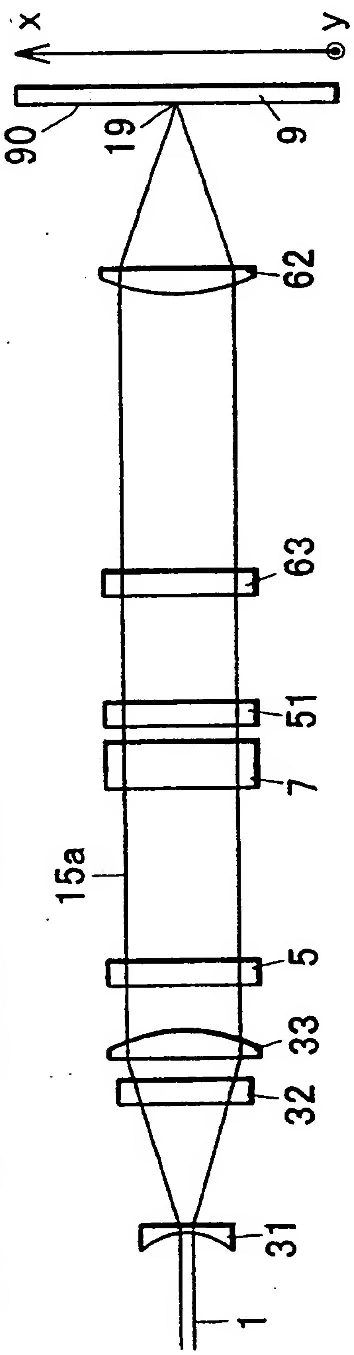


图 18A　聚光方向（x方向）

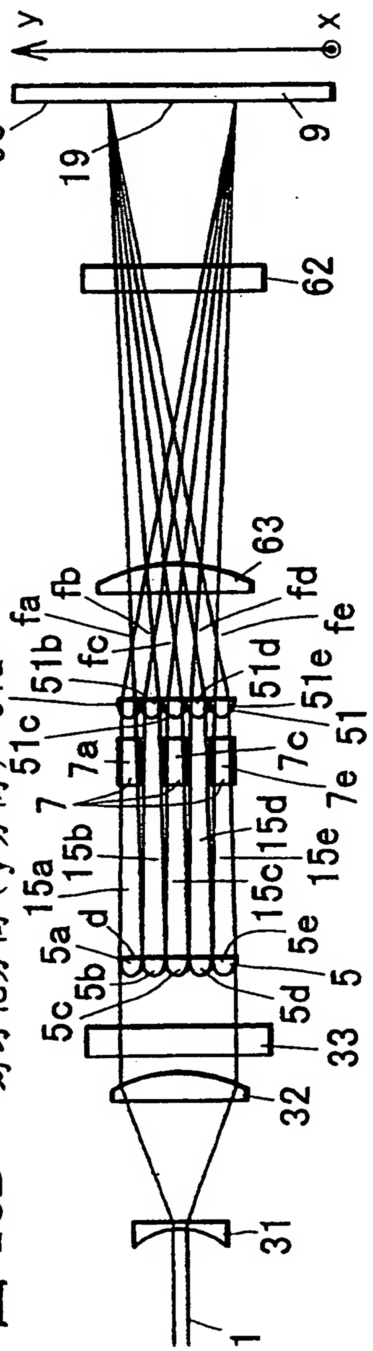


图 18B　均匀化方向（y方向）

图19

均匀化方向（y方向）

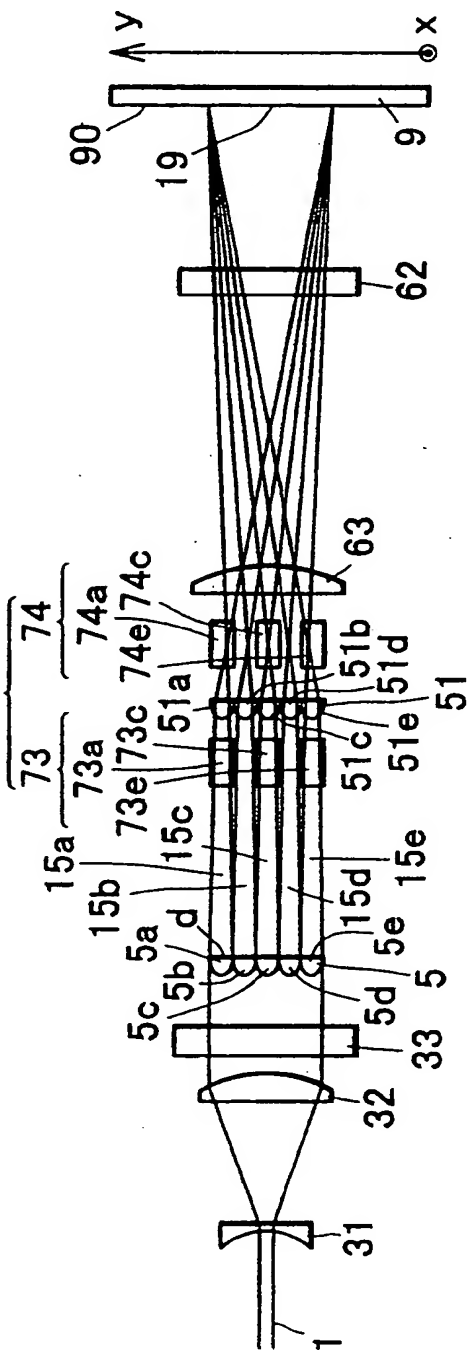


图20

均匀化方向（y方向）

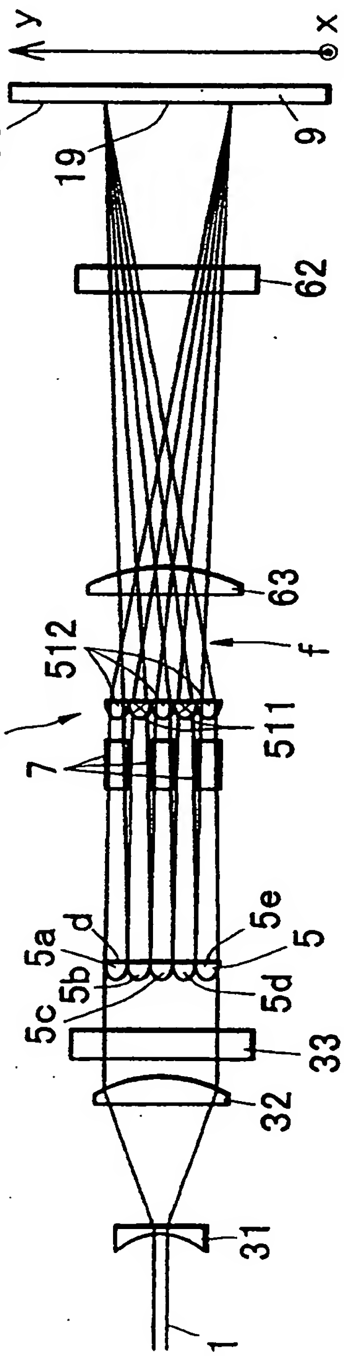


图 21A 聚光方向（x方向）

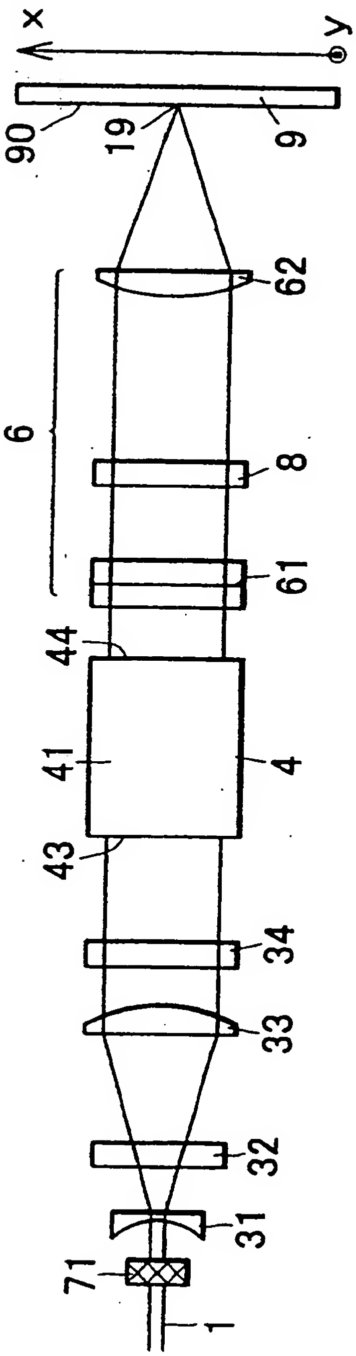


图 21B 均匀化方向（y方向）

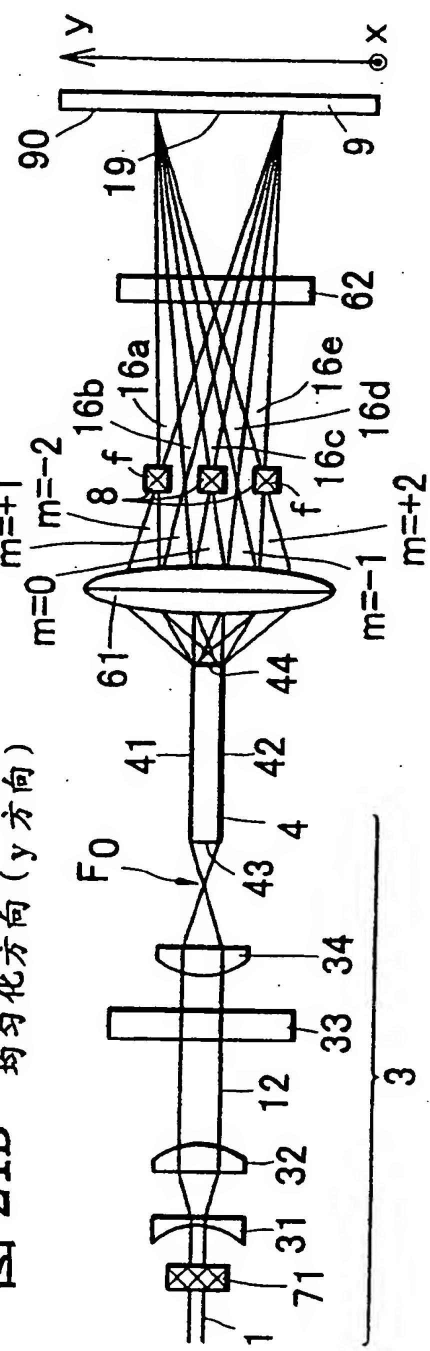
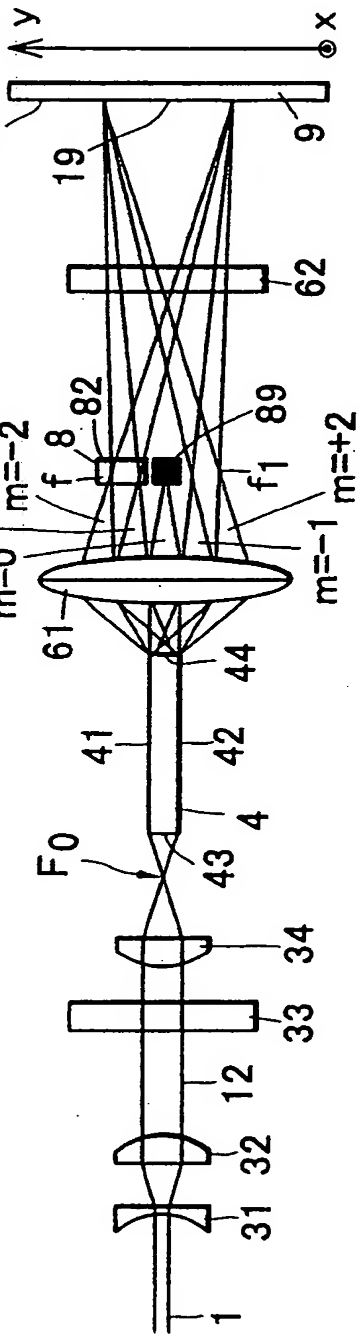
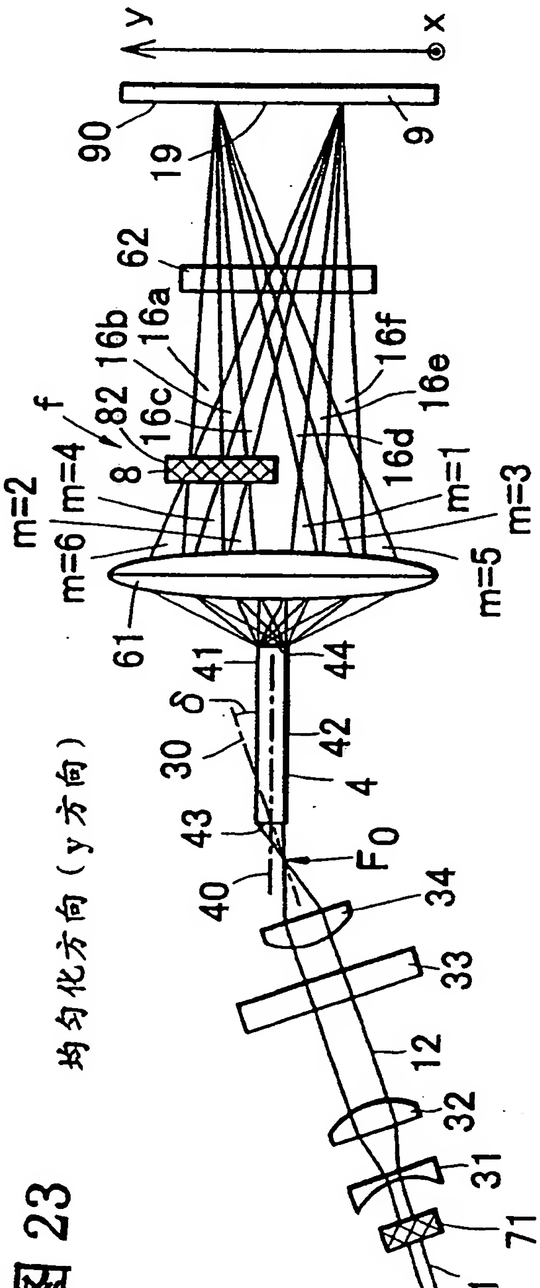


图22 均匀化方向（y方向）





均匀化方向（y方向）

图 23

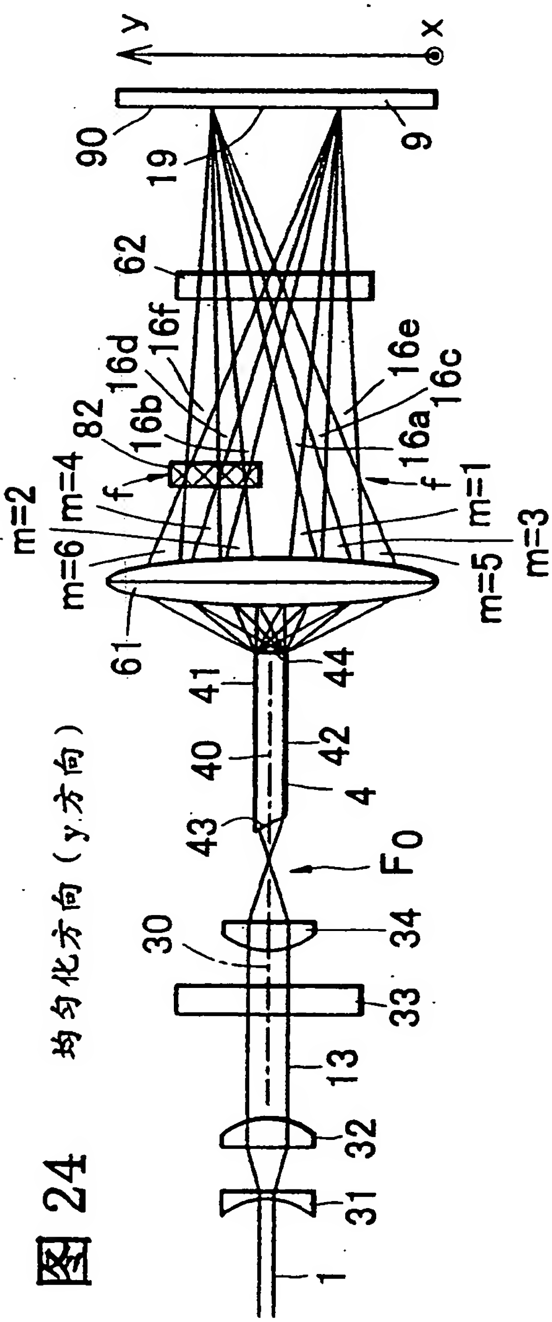
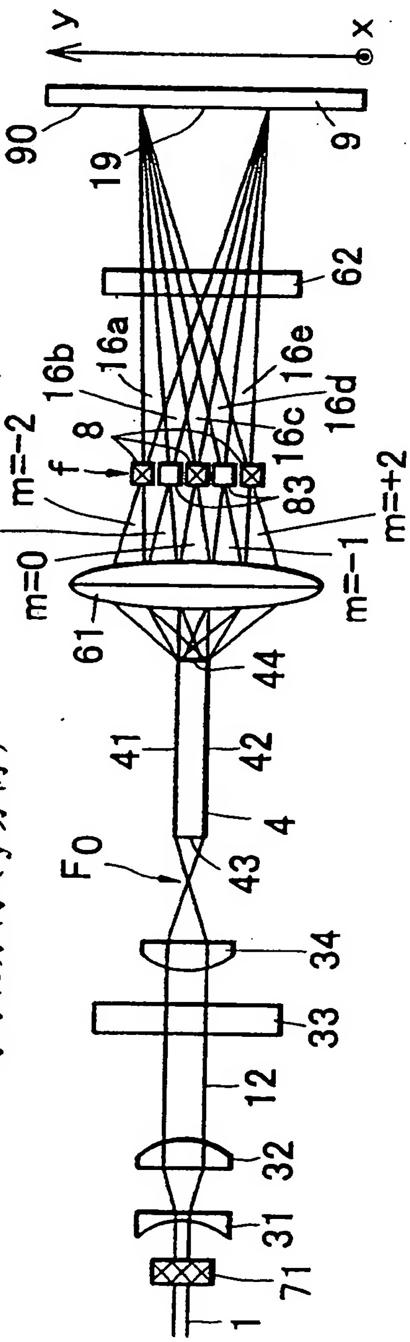


图 24 均匀化方向（y方向）

图 25

均匀化方向（y方向）



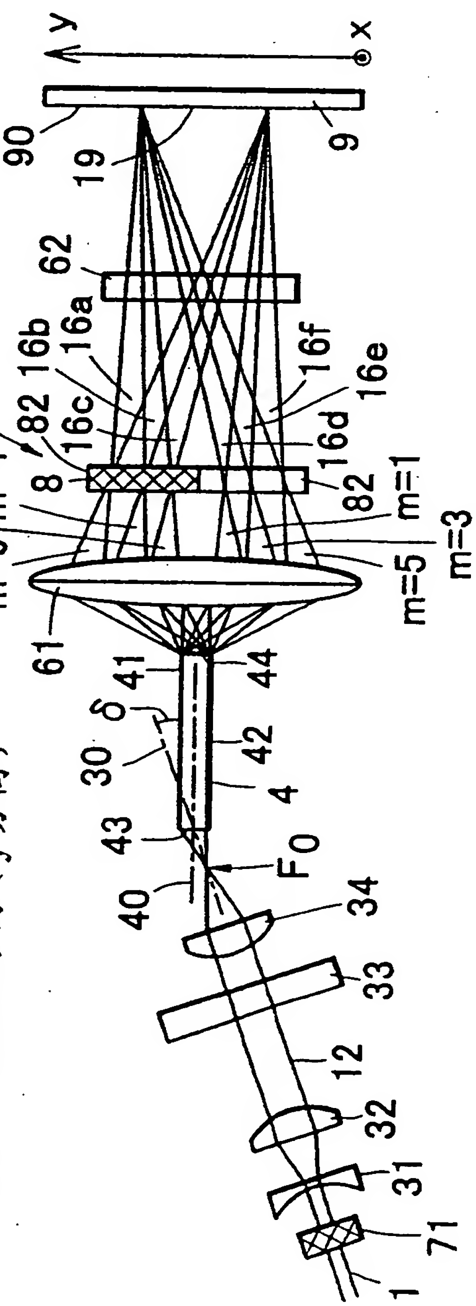


图 26　均匀化方向（y方向）

图27A　聚光方向（x方向）

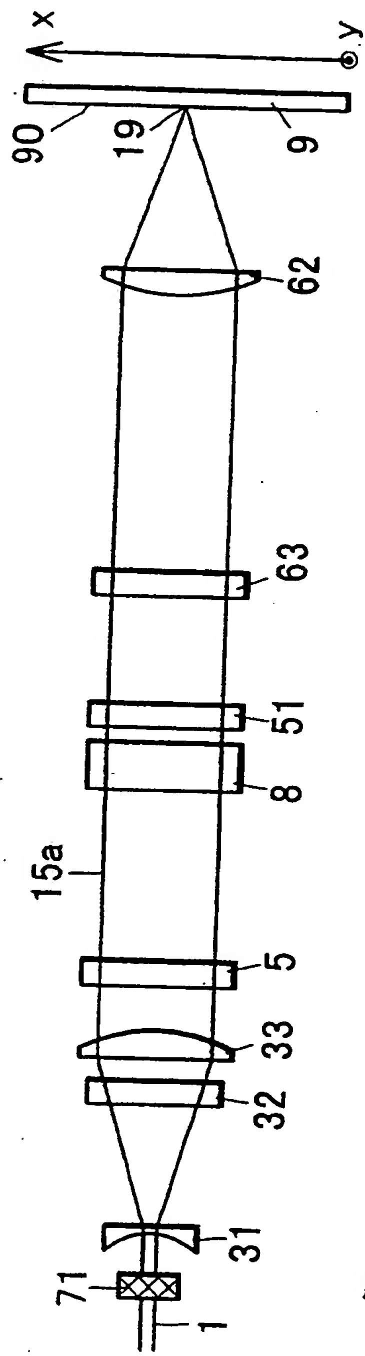
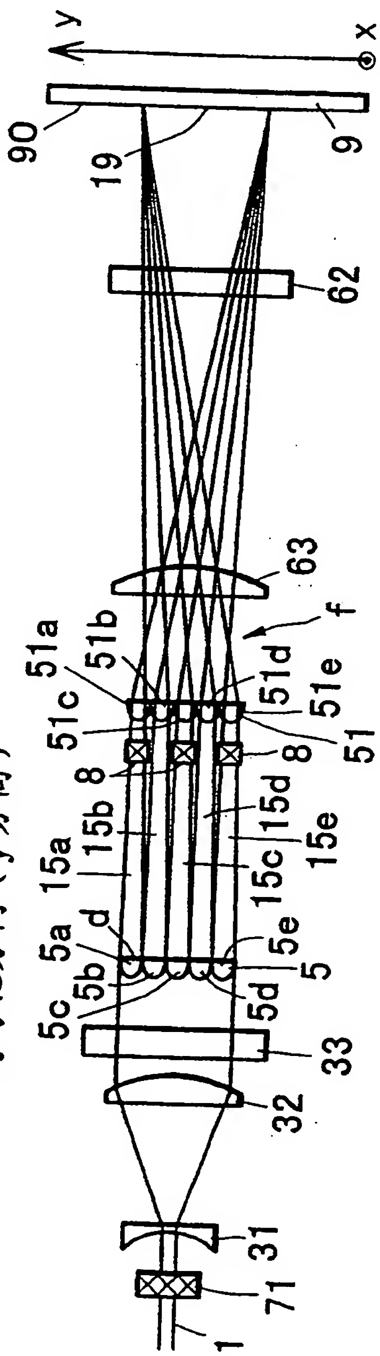


图27B　均匀化方向（y方向）



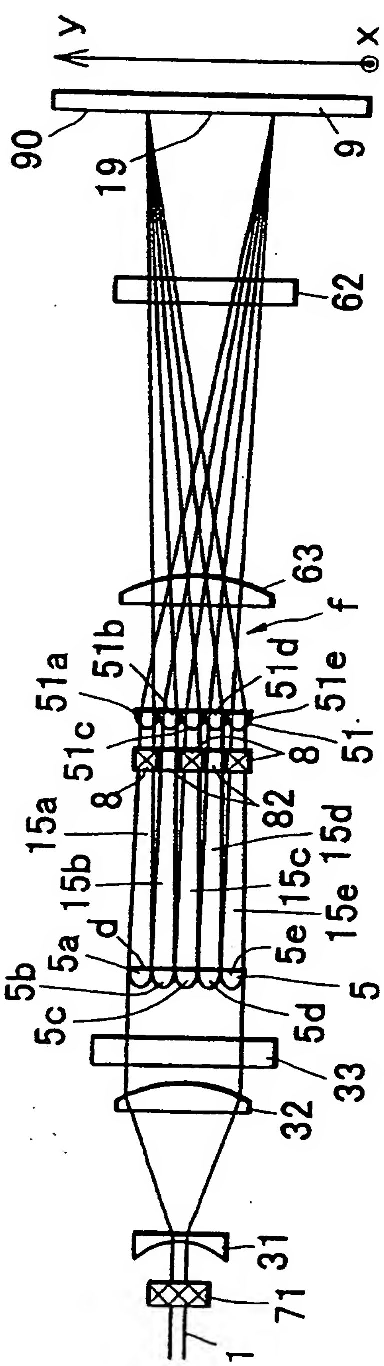


图28 均匀化方向（y方向）

图29

均匀化方向（y方向）

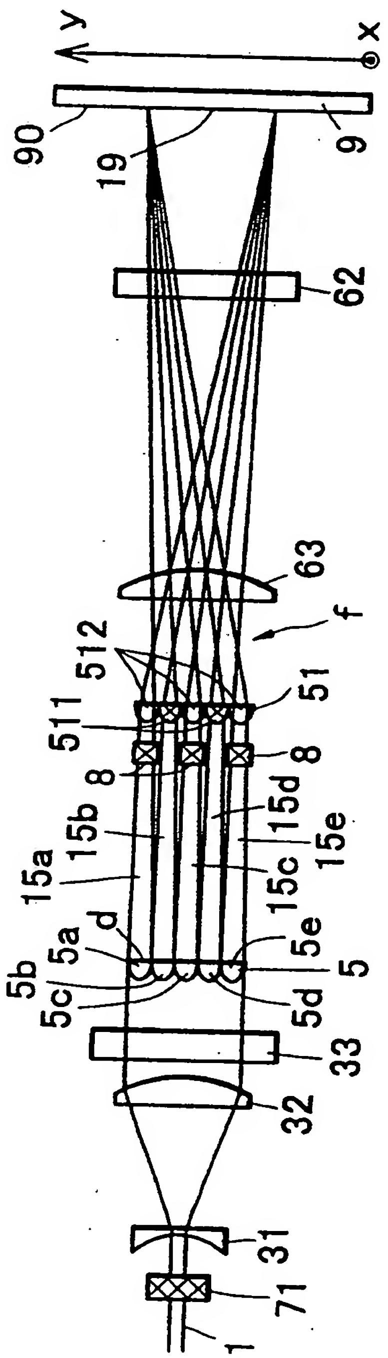


图 30A 聚光方向（x方向）

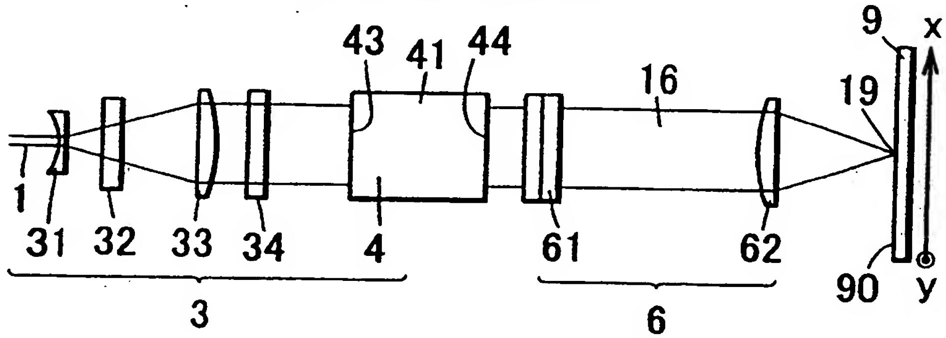


图 30B 均匀化方向（y方向）

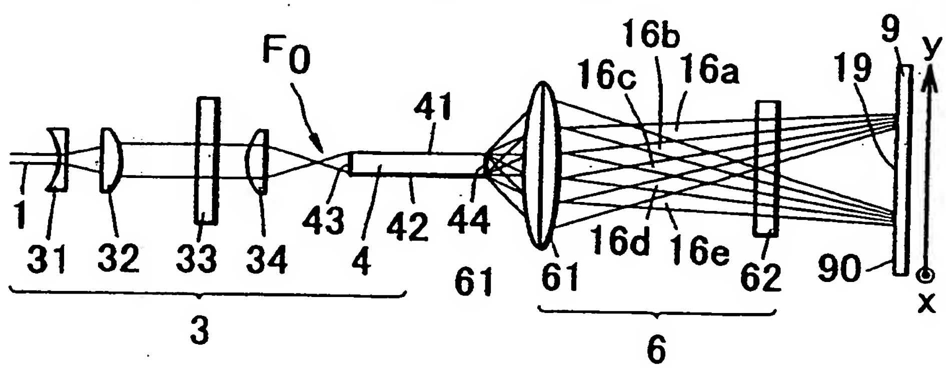


图 30C

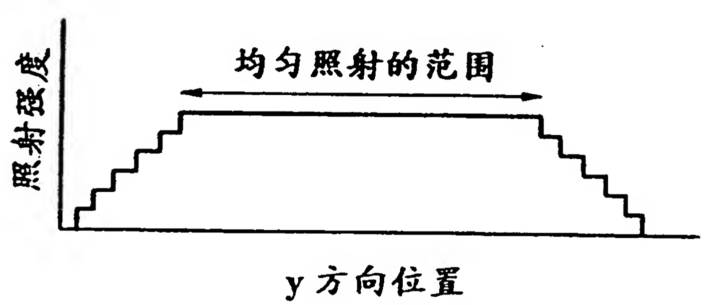


图 31A 聚光方向（x方向）

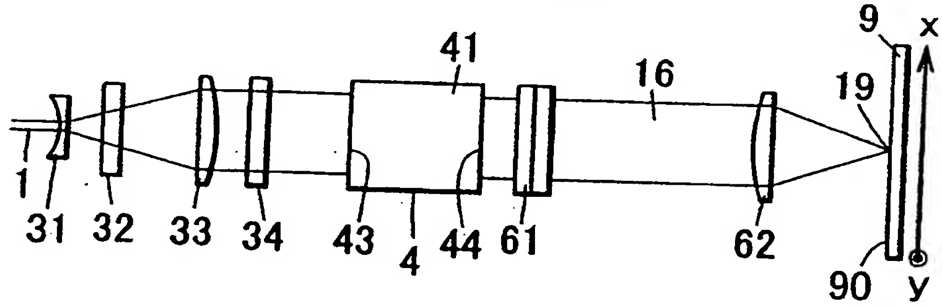


图 31B 均匀化方向（y方向）

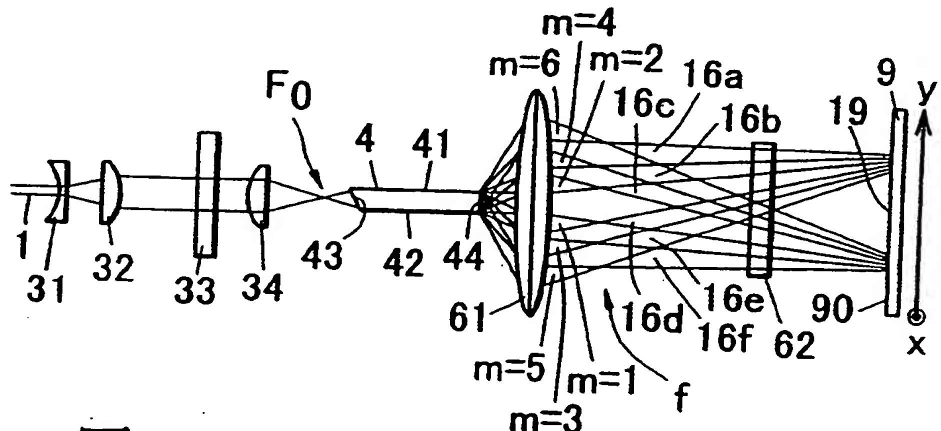


图 31C

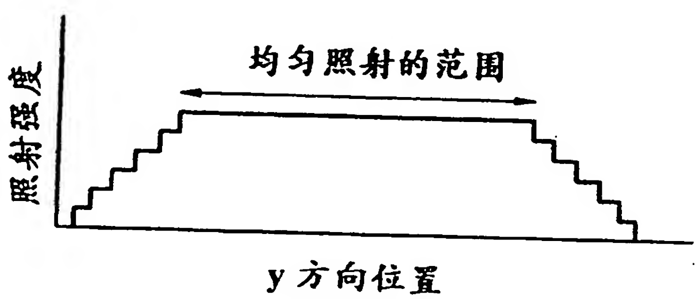


图 32A 聚光方向（x方向）

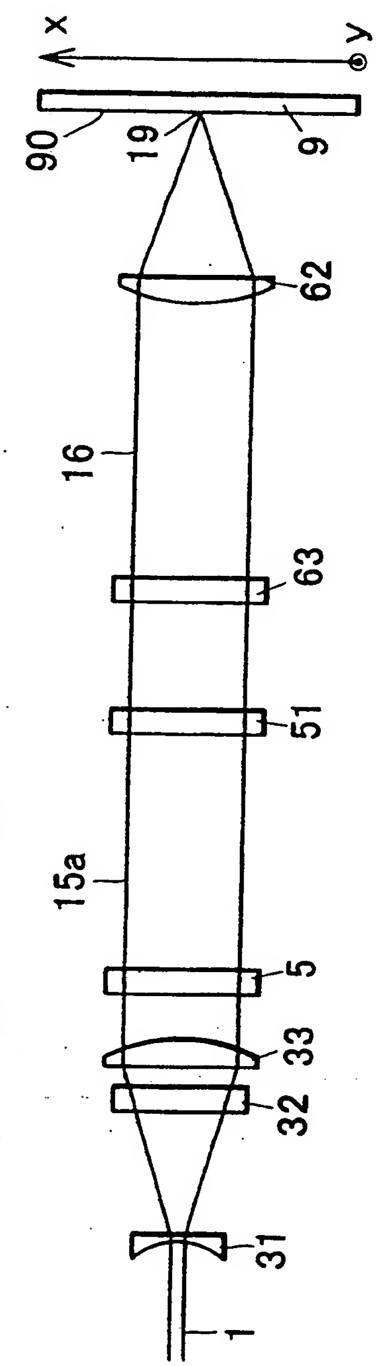


图 32B 均匀化方向（y方向）

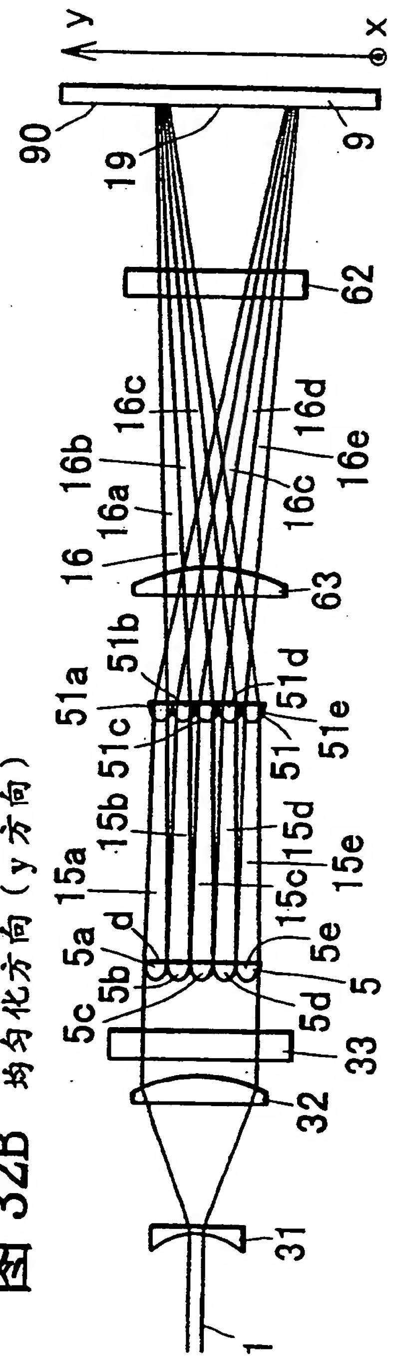


图 33A 聚光方向（x方向）

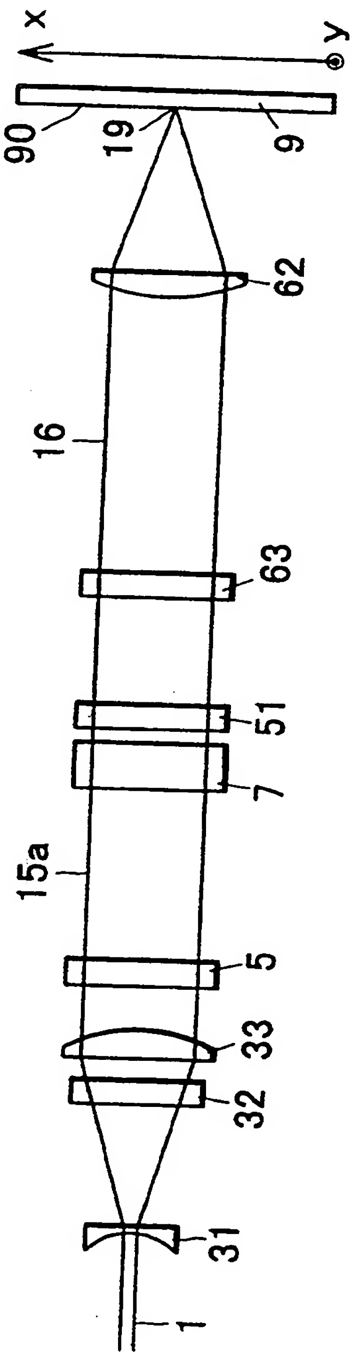


图 33B 均匀化方向（y方向）

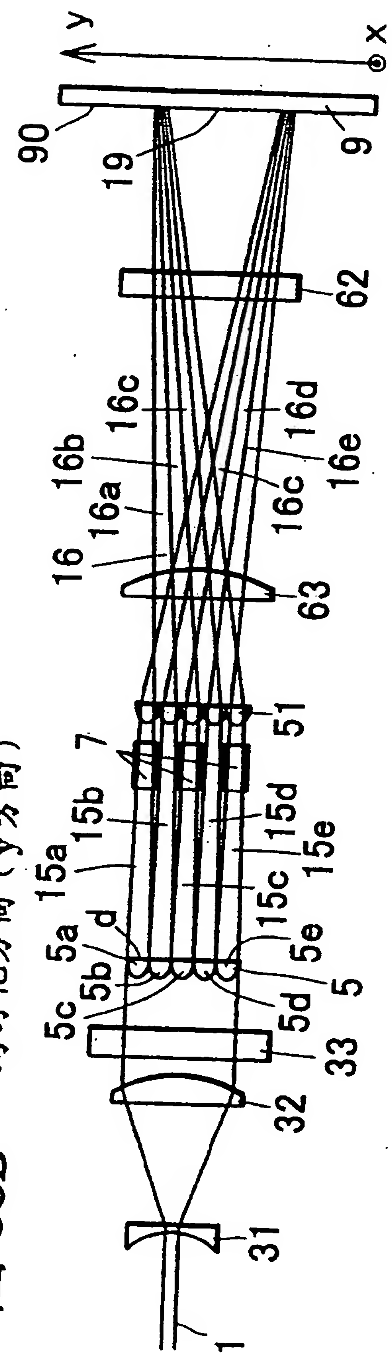
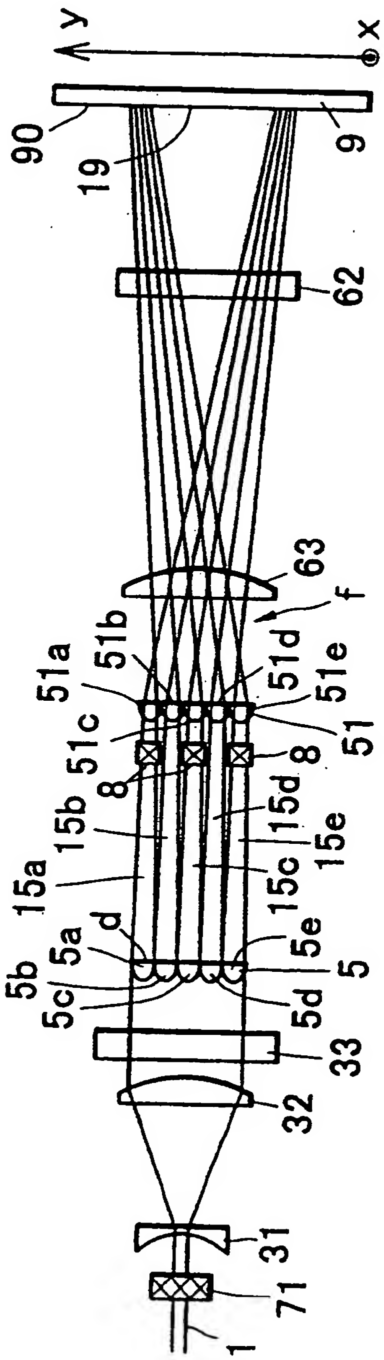


图 34 均匀化方向（y方向）



OPTICAL SYSTEM FOR UNIFORM IRRADIATION OF LASER BEAM

Field of the Invention

The present invention relates to an optical system for uniform irradiation of laser beam which improves the uniformity of the intensity distribution of the laser beam on an irradiated area during the laser treatment for an irradiated object.

Background of the Invention

As an example in which heat treatment by laser radiation is employed, the approach of forming the amorphous silicon film beforehand by the vapor deposition, such as CVD, on the suitable substrate, for example, a glass substrate, on the occasion of manufacture of the polysilicon film, and scanning and polycrystallizing this amorphous silicon film by the laser beam is learned. For example, the approach has been disclosed in U.S. Patent No. 5,529,951, in which the non-crystal was formed on the polysilicon layer by evaporating the amorphous silicon on the circuit intergrant again and irradiating the necessary locations with an excimer laser beam in the assembly of a semiconductor integrated circuit. This U.S. Patent has used a fly's-eye lens or a prism as an uniform unit to make the intensity distribution of the excimer laser beam on entire subquadrate area uniform in order to increase the irradiated area.

We also know the approach of polycrystallizing the silicon film on a large substrate, comprising for example, condensing the laser beam from a laser source on the amorphous silicon film with a lens and carrying out laser radiation during which the silicon film is made to be crystallized in the process of coagulation while melting locally. The distribution of axial intensity of the beam at an irradiated location is usually the Gaussian distribution with optically axial symmetry depending on a beam profile of the laser source. The polysilicon film formed by the irradiation of such a beam has a very low uniformity when crystallized in its surface direction, and therefore it is difficult to be used as a semiconductor substrate in the manufacture of a thin film transistor.

Furthermore, the technique is also known in which the excimer laser with short wavelength, the profile of which is made rectangle-like distribution on the irradiated area, is used to irradiate and heat the semiconductor film. In JP 11-16851 and JP 10-333077, the laser beam from an oscillator passes through two cylindrical lens arrays which intersect mutually in a surface perpendicular to an optical axis, and is imaged on the semiconductor film surface by disposing a focusing lens ahead. The cylindrical lens array is an optical element which divides a beam of light into a plurality of beams of light, in which a plurality of tiny cylindrical lenses are configured to be in parallel each other and vertical to the optical axis.

In above mentioned approaches, the laser beam which takes Gaussian distribution or takes pure pattern passes through two cylindrical lens arrays and the uniform intensity distribution can be got in two orthogonal directions. The shape of the irradiating beam on the semiconductor film surface has different widths in two orthogonal directions on the semiconductor surface. By this approach, the irradiating laser beam sweeps in width direction of the narrow side, thus the polycrystalline area with a constant width equivalent to that of the long side has been formed repeatedly on the

semiconductor film.

However if the laser beam from the laser source is divided by such a cylindrical lens array and then is superposed on the irradiated area, the optical interference of the laser beam will arise on the irradiated area, and thus the interference pattern with strong and weak intensity repeatedly will be formed.

Because the interference caused by the superposition of a plurality of beams on the irradiated area will affect the crystal growth on this area. That is, when the amorphous semiconductor film is heated and crystallized using a rectangle-like irradiating laser beam, since the irradiating beam is moving along the width direction of the narrow side, the intensity distribution of the length direction orthogonal to the moving direction influences the crystal growth greatly. The intensity distribution of this direction is nonuniform and the interference pattern is big, which is disadvantageous to the growth of the crystal grain of the silicon film.

Several approaches used to remove the nonuniformity of the irradiating intensity of the laser resulted in this interference have been proposed. In JP 2001-127003, an optical system has been disclosed, wherein the laser beam from a light source was made to be the collimated light by a collimator and irradiated a mirror with step-like reflecting faces, and the beams divided by this mirror passed through the cylindrical lens array for superposition and the cylindrical lens array for convergence and then irradiated the irradiated area. With the steps between each of the reflecting faces, this optical system establishes the optical path difference larger than the interference length of the laser beam for the divided beam, thus preventing the interference between the divided beams on the irradiated area.

In addition, JP 2001-244213 has disclosed the technique, in which the laser beam from the light source was made to be the collimated light by the collimator and irradiated a plurality of tiny mirrors, and the reflected lights from each of mirrors irradiated the irradiated area and were superposed, thus preventing the interference by guaranteeing the optical path difference of the laser beam reflected by each of plane mirrors above the interference length.

The above mentioned technique for beam uniformity uses the mirror with a plurality of reflecting faces to establish the optical path difference so as to prevent the interference arising when the laser beam from the same light source is divided and then superposed on the irradiated area, but these optical systems require the special mirror. In particular, the optical system in JP 2001-244213 requires the configuration that makes the optical axis of the optical system based on the mirror bent. In order to enable each of the divided beams to irradiate the irradiated area accurately, it is required that each of mirrors in the optical system meet the special position relationship. Therefore, the configuration with a plurality of mirrors becomes complex and there is a problem that the degree of freedom of the optical system configured as heat treatment device is reduced. Especially, when the optical path difference is established for all of the divided beams, for the laser oscillation source with large temporal interference distance, the device will become huge and complex, which is impractical and difficult for optical adjustment.

Summary of the Invention

In view of above described problem, the object of the present invention is to provide an optical system for uniform irradiation of laser beam, which divides the laser beam from a light source and makes the divided beams superposed on the irradiated area and then forms the uniform intensity distribution of the irradiating beam on the irradiated area. It can prevent the interference between the divided beams caused by superposition and obtain the uniformity of the irradiating beam.

The another object of the present invention is to provide an optical system for uniform irradiation, which is used to prevent such a interference and makes the structure and adjustment of the uniformity of the irradiating beam simple and easy.

The still another object of the present invention is to provide an optical system, which is suitable for being a laser heating device to polycrystallize the amorphous silicon film in a irradiated object when irradiating it and can form the amorphous silicon film with less defects on the crystalline area.

The optical system for uniform irradiation of laser beam according to the invention consists of the following parts: a laser beam division unit which divides the laser beam from a laser source into a plurality of divided beams spatially in the beam cross section; a superposition and irradiation unit which makes a plurality of the divided beams superposed and irradiated on the irradiated area; and an uniformity unit which makes the intensity of the beam on the irradiated area uniform. The laser beam division unit enables the divided beam to have a width of more than 1/2 times of the spatial interference distance in the direction of the cross section of the laser beam from the light source. Even though the divided beams defined by such a beam width are superposed on the irradiated area by means of the superposition and irradiation unit, it can also alleviate the mutual interference among a plurality of beams so that the intensity distribution on the irradiated area is uniform.

In addition to the laser beam division unit which can divide the laser beam from the laser source into a plurality of the divided beams spatially in the beam cross section and the superposition and irradiation unit which makes a plurality of the divided beams superposed and irradiated on the irradiated area, this optical system for uniform irradiation of laser beam further comprises the uniformity unit which makes the intensity of the beam on the irradiated area uniform. A type of the uniformity unit comprises an optical delay unit which makes one of the adjacent divided beams relative to the other be delayed a longer distance than the temporal interference distance of the laser beam. The optical delay unit is used to prevent the interference occurring between the adjacent divided beams on the irradiated area and make the intensity distribution of the beam uniform.

The other uniformity unit according to the present invention comprises an optical rotatory unit which makes a polarization angle between the adjacent divided beams divided by the laser beam division unit essentially orthogonal. By making the polarization angle between the divided beams mutually orthogonal, the optical rotatory unit can alleviate the interference between the divided beams occurring when superposing each of the adjacent divided beams on the irradiated area, so as to make the intensity distribution of the irradiation uniform.

The optical system according to the present invention has the advantage of making the intensity distribution of the irradiation uniform extremely because it can reduce the factor about the spatial interference distance in the direction of the cross section of the laser beam and the factor about the temporal interference distance in the direction of the optical axis at the same time.

The superposition and irradiation unit according to the present invention can make the divided laser beams be shifted or misaligned each other on the irradiated area so as to form the duplicated irradiating beams. When each of the divided beams divided by the laser beam division unit pass through the superposition and irradiation unit, they will be optically misaligned and irradiate the irradiated area, which will reduce the interference between the divided beams on the irradiated area. The superposition and irradiation unit for duplicated shift or misalignment can be simply performed, which can reduce the interference caused by the factor about the spatial interference distance and the factor about the temporal interference distance in the direction of the optical axis at the same time.

The optical system for uniform irradiation of laser beam according to the present invention can take the irradiated area as a semiconductor film formed on a noncrystal or polycrystal in a substrate and can use the semiconductor film to anneal.

Detailed Description of the Drawings

The accompanying drawings will be described briefly as follow.

Fig. 1A and 1B are schematic diagrams illustrating the configuration of an optical system for uniform irradiation of laser beam using a waveguide according to an embodiment of the present invention, which represent the diagrams viewed from y-direction and x-direction respectively.

Fig. 2 is a cross section view illustrating the division form of the laser beam in the waveguide.

Fig. 3A illustrates the configuration of the divided beams in the cross section of the laser beam when the laser beam is divided in the waveguide; Fig. 3B illustrates the configuration of the divided beam at the exit face of the waveguide.

Fig. 4 is a graph illustrating the intensity distribution and visibility of the superposed irradiating beam when two adjacent divided beams divided by the waveguide are superposed on the irradiated area (d=s).

Fig. 5 is a schematic diagram illustrating the definition of the spatial interference distance of the laser beam.

Fig. 6 is a graph illustrating the intensity distribution and visibility of the superposed irradiating beam when 7 divided beams divided by the waveguide are superposed on the irradiated area (d=s).

Fig. 7 is a graph of the optical path difference versus the visibility of the laser beam.

Fig. 8A and 8B are schematic diagrams illustrating the configuration of an optical system for uniform irradiation of laser beam using a cylindrical lens array as a laser beam division unit according to the other embodiment of the present invention, which are equivalent to Fig. 1A and 1B.

Fig. 9A illustrates the configuration of the divided beams in the cross section of the laser beam when using the cylindrical lens array as the laser beam division unit; Fig. 9B also illustrates the configuration of the divided beam at the exit face of the waveguide.

Fig. 10 is a graph illustrating the intensity distribution and visibility of the superposed irradiating beam when two adjacent divided beams divided by the cylindrical lens array are superposed on the irradiated area (d=s).

Fig. 11 is a graph illustrating the intensity distribution and visibility of the superposed irradiating beam when 7 divided beams divided by the cylindrical lens array are superposed on the irradiated area (d=s).

Fig. 12A and 12B are schematic diagrams illustrating an optical system for uniform irradiation of laser beam using a waveguide as a laser beam division unit and a retardation plate with light transmission as an optical delay unit according to an embodiment of the present invention, which are similar to Fig. 1A and 1B.

Fig. 13 is a variant example of the optical system shown in Fig. 12, which illustrates an optical system obstructing the divided beams that aren't reflected between the reflecting faces of the waveguide but pass through; it's similar to Fig. 12B.

Fig. 14 is a schematic diagram illustrating the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide in the optical system for uniform irradiation of laser beam according to the other embodiment of the present invention, which is similar to Fig. 12B.

Fig. 15 is a schematic diagram illustrating the laser beam division in the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide, which is similar to Fig. 14.

Fig. 16A and 16B are schematic diagrams illustrating the division state of the laser beam in the waveguide with the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide as shown in Fig. 15; they are similar to Fig. 3A and 3B.

Fig. 17 is a schematic diagram illustrating the configuration of the incident face of the waveguide intersecting obliquely the central axis of the waveguide in the optical system for uniform irradiation of laser beam according to the other embodiment of the present invention.
Fig. 18A and 18B illustrate the optical systems for uniform irradiation of laser beam according to

the other embodiments of the present invention, which apply the retardation plate to the cylindrical lens array for division; they are similar to Fig. 8A and 8B.

Fig. 19 is similar to Fig. 18B, in which two retardation plates are disposed in front and rear of the cylindrical lens array for duplication.

Fig. 20 illustrates the focus modulation to the cylindrical lens array for duplication; it's similar to Fig. 18B.

Fig. 21 A and 21B illustrate an example of using the waveguide as the laser beam division unit and the optical rotatory plate as the uniformity unit according to the other embodiments of the present invention, which are similar to Fig. 1A and 1B respectively.

Fig. 22 is a variant example of Fig. 21B, illustrating the optical system which obstructs the divided beams that aren't reflected between the reflecting faces of the waveguide but pass through; it's similar to Fig. 21B.

Fig. 23 is a schematic diagram illustrating the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide in the optical system for uniform irradiation of laser beam according to the other embodiment of the present invention, which is similar to Fig. 21B.

Fig. 24 is a schematic diagram illustrating laser beam division in the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide, which is similar to Fig. 23.

Fig. 25 is a variant example of Fig. 21, illustrating the optical system for uniform irradiation of laser beam which comprises a half-wavelength plate and an optical path length compensating unit.

Fig. 26 is a variant example of Fig. 23, illustrating the optical system for uniform irradiation of laser beam which comprises a half-wavelength plate and an optical path length compensating unit.

Fig. 27A and 27B are schematic diagrams illustrating the optical system for uniform irradiation of laser beam which employs the cylindrical lens array for division and the half-wavelength plate; they are similar to Fig. 1A and 1B.

Fig. 28 illustrates the optical system which disposes alternately the half-wavelength plate and the retardation plate for the divided beams shown in Fig. 27A and 27B; it's similar to Fig. 27B.

Fig. 29 is similar to Fig. 27B, in which two retardation plates are disposed in front and rear of the cylindrical lens array for duplication.

Fig. 30A and 30B are schematic diagrams illustrating the optical system for uniform irradiation of laser beam in which each of the divided beams is shifted, i.e. misaligned and duplicated, via a

superposition and irradiation unit according to the other embodiments of the present invention, viewed from y-direction and x-direction respectively; Fig. 30C illustrates the profile of intensity of the irradiating beam in the optical system shown in Fig. 30A and 30B.

Fig. 31A, 31B and 31C are similar to Fig. 30A, 30B and 30C, which illustrate the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide.

Fig. 32A and 32B are schematic diagrams illustrating the optical system which comprises the superposition and irradiation unit for shifting and duplicating the divided beams on the irradiated area; they are similar to Fig. 8A and 8B respectively.

Fig. 33A and 33B are schematic diagrams illustrating the optical system which comprises the superposition and irradiation unit for shifting and duplicating the divided beams on the irradiated area; they are similar to Fig. 18A and 18B respectively.

Fig. 34 is a schematic diagram illustrating the optical system which comprises the superposition and irradiation unit for shifting and duplicating the divided beams on the irradiated area; it's similar to Fig. 27.

Detailed Description of the Invention

A laser beam division unit of the optical system according to the present invention divides the laser beam from a laser source into a plurality of divided beams which will pass through a superposition and irradiation unit. The superposition and irradiation unit makes the divided beams superposed and irradiated on the irradiated area. Herein the laser beam division unit enables each of the divided beams to have a width of more than 1/2 times of the spatial interference distance in the direction of a cross section of the laser beam, thus preventing the interference between the divided beams on the irradiated area and making the intensity distribution of the irradiating beam uniform.

Before being divided, two divided beams are readily interfered if they are adjacent to each other in the cross section of this laser beam. However, the interference can be reduced by means of making the width of each divided beam more than 1/2 times of the spatial interference distance.

The width of each of the above-mentioned divided beams is defined as that of the divided beam in the exit face of the laser beam division unit and in this case, the spatial interference distance refers to the spatial interference distance in the cross section when the laser beam from the light source is projected on the location of the exit face. It will be described in more detail hereinafter that the spatial interference distance relates to the interference occurring when two branches divided from the laser beam are superposed on the irradiated area, and the visibility to be described below is the minimum overlap distance of two divided beams when it becomes to 1/e.

In the present invention, the ratio of the divided beam width to the spatial interference distance in the direction of the cross section of the beam is more than 1/2, preferably more than $1/\sqrt{2}$, more preferably more than 1. That is, the width of the divided beam divided by the laser beam division

unit is desired to set to be more than $1/\sqrt{2}$ times of the spatial interference distance, especially 1 times or more.

The upper limit of the divided beam width is decided by the number of the divided beams, but the number of the divided beams is at least 5, and preferably 7 or more. Although it is more effective in flattening the intensity of the irradiating beam if the number of the divided beams is larger, it is not desirable that the number of divided beams is so large that the ratio of the divided beam width to the spatial interference distance becomes less than 1/2. The practical number of the divided beams is 5-7 and the ratio of the divided beam width to the spatial interference distance is set to 1 times or more.

The laser beam division unit divides the laser beam from the laser source and specifies the laser beam width, and the laser beam division unit can use the waveguide or the cylindrical lens array which divides the laser beam into the divided beams with said number in any one direction in the surface perpendicular to the optical axis.

The waveguide can utilize a hollow body or a solid light-transmission body with two reflecting faces mutually opposite. The hollow waveguide can utilize the object that arranges two mirror faces oppositely at certain spacing.

The solid waveguide is the light-transmission body which is transparent plate-like, and makes major faces on sides as the mirror faces and uses the two end faces for incident and exit irradiation. Such a waveguide can usually use the optical glass plate.

In the waveguide, the condenser lens which performs incidence of the exit beam from the laser source between the reflecting faces in the waveguide is included in the laser beam division unit.

From the exit face of the waveguide, we can obtain the divided beams which aren't reflected by the reflecting faces but pass through the waveguide, and two groups of the divided beams which are reflected from the opposite reflecting faces each time. The number of the divided beams will increase by 2 whenever the number of the times that the incident beams are reflected from the reflecting faces increases once.

However, the cylindrical lens array used as the laser beam division unit, in which a plurality of the cylindrical lenses with the cylindrical shape and the cross section taking the form of convex lens are arranged in parallel in the direction essentially orthogonal to the optical axis, can obtain the divided beams corresponding to each of the tiny cylindrical lenses. In the laser beam division unit which uses the cylindrical lens array, a collimator is preferably included so that the collimated light is incident in the cylindrical lens array.

The other form of the optical system according to the present invention comprises an uniformity unit comprising a optical delay unit and a rotatory unit.

In the present invention, the optical delay unit has the function that make one of the adjacent

divided beams divided by the laser beam division unit relative to the other be delayed a longer distance than the temporal interference distance of the laser beam, thereby reducing and even preventing the interference occurring between the adjacent divided beams.

The optical delay unit preferably utilizes the light-transmission body for delaying beam, i.e. a retardation plate, which is inserted in the spatially separate optical path of each of the divided beams divided by the laser beam division unit. At this moment, when each of the divided beams are projected reversely toward the laser beam from the light source, the retardation plate is inserted in at least either of the adjacent divided beams so that the optical path difference is established between the adjacent divided beams.

The retardation plate makes the optical path difference of the adjacent divided beams larger than the temporal interference distance of the laser beam, thereby preventing the interference between the divided beams when a plurality of the separate divided beams irradiate the irradiated area and are superposed. The optical path difference is determined by the thickness of the retardation plate (i.e. light-transmission length), the difference of refractive indexes of the retardation plate and air.

Based on the laser beam from the laser source, the retardation plate is inserted in the arrangement of every other one of the adjacent divided beams divided from the laser beam to produce the optical path difference mutually, thus producing the phase difference.

In the present invention, the uniformity unit further comprises the optical rotatory unit, which makes a polarization angle between the adjacent divided beams divided by the laser beam division unit essentially orthogonal so that the irradiating beam with profile of the required uniform intensity distribution is formed when the divided beams are superposed on the irradiated area. In this embodiment, by means of making the polarization angle between the divided beams mutually orthogonal, the optical rotatory unit can reduce the interference between the divided beams occurring when superposing each of the adjacent divided beams on the irradiated area so as to make the intensity distribution of the irradiation uniform.

Based on the laser beam from the laser source, the optical rotatory plate is inserted in the arrangement of every other one of the adjacent divided beams divided from the laser beam to produce an angle of 90 degrees between the polarization planes.

An example of the optical rotatory unit is a crystalline plate using crystal, which makes the polarization plane passing the divided beam relative to the polarization plane of the other of the divided beams be rotated an angle of 90 degrees. Such an optical rotatory unit is known as the half-wavelength plate. Herein the so-called "essentially orthogonal" allows the angle deviation of ±30 degrees when the polarization plane of one of the divided beams is orthogonal to the polarization plane of the other of the divided beams. In this way, even though the polarization planes of two divided beams is not orthogonal, but intersect obliquely, the interference between two divided beams is also reduced.

Other rotatory units can also use a Fresnel rhomb.

Furthermore, because the optical rotatory unit is insert in only one of the adjacent divided beams, the optical path difference relative to the other of the divided beams is produced, which causes the deviation of imaging location of these divided beams on the irradiated area. So, the optical path length compensating plate is inserted in the other of the divided beams so that the optical path length of the other of the divided beams in which the optical rotatory unit isn't inserted is essentially equal to that of this divided beam, thereby making the imaging of this divided beam and the other of the divided beams on the irradiated area distinct and making the intensity distribution of the superposed irradiating beam uniform.

For the configuration of the uniformity unit (i.e. the retardation plate and the optical rotatory plate), the superposition and irradiation unit comprises a duplication (image transferring) lens for duplicating the divided beams from the laser beam on the irradiated area. When the spatially separate regions of a plurality of the divided beams are formed by means of the duplication lens, the uniformity unit, such as the retardation plate etc. is inserted in such separate regions. For example, when the laser beam division unit is a waveguide, the retardation plate is disposed in the focal position where each of the divided beams converges.

For the simplification of the uniformity unit, it is expected that the structure or configuration of the waveguide doesn't produce the divided beams which aren't reflected but pass. As described below, this configuration can alleviate the interference on the irradiated area by inserting a single retardation plate or optical rotatory plate in a preset group of the divided beams without inserting in another group of the divided beams. It has the advantage of making the configuration of a single optical delay unit simple.

For this reason, it is expected that a shelter is inserted in the divided beams of the incident laser beam which aren't reflected from inner reflecting faces but pass through the waveguide.

Other forms can take the structure in which the laser beam incident in the waveguide is made to be asymmetrically incident relative to the central axis of the waveguide. Thereby, in the waveguide, the optical axis of the laser beam incident in the waveguide is made to intersect obliquely the central axis between the reflecting faces of the waveguide so that the divided beams which aren't reflected from any reflecting faces but pass trough can't be produced.

Other forms use the above mentioned solid body with light transmission in the waveguide, however, the structure that the incident face and the central axis of the waveguide are intersected obliquely is employed, and the oblique incident face makes the incident light refracted. These forms have the advantage of utilizing all of the divided beams in the irradiation compared to the structure obstructing the divided beams which aren't reflected but pass through.

Since the optical paths at exit end of the cylindrical lens array are separate each other when the laser beam division unit is cylindrical lens array, other configurations of the uniformity unit can dispose the retardation plate and the optical rotatory plate in the optical path of the beam. At this time, several small retardation plates and optical rotatory plates can be disposed in every other one

of the beams divided by the cylindrical lens array.

In this way, a portion of several divided beams pass through the uniformity unit, and the superposition and irradiation unit makes the divided beams superposed and irradiated on the irradiated area. The projection of the irradiating laser beam shapes as a rectangle or straight line, and the intensity distribution of the irradiating beam in length direction is uniform.

In an embodiment of the present invention, the superposition and irradiation unit further comprises the function of making each of the divided beams be shifted mutually and duplicated to form the irradiating beam. The superposition and irradiation unit makes the divided beams divided by the division unit superposed and irradiated and shaped as rectangle or straight line on the irradiated area. But in this embodiment, especially the nonuniform intensity distribution is eliminated in length direction by making several divided beams be shifted in length direction of the irradiating beam. Such a superposition and irradiation unit preferably utilizes the cylindrical lens with lens aberration.

The optical system for uniform irradiation of laser beam according to the embodiments of the present invention is suitable for using in the annealing device, in which heating fusion of the amorphous silicon or polysilicon film formed by chemical vapor deposition on glass substrate is performed to polycrystallize or make it grow up to be a bigger and rougher crystal. Here the annealing is not only used for irradiating the solid film with laser to directly crystallize or re-crystallize, but also comprises temporary fusion of the solid film with laser and its crystallization in the subsequent coagulation process of the fusing film.

In the present invention, the laser source comprises a solid laser and a semiconductor laser, and the laser beam comprises the first harmonic and the higher harmonic in the solid laser and semiconductor laser. Especially when the irradiated area is a silicon semiconductor film, in particular amorphous silicon film, it is expected to utilize the second higher harmonic (double wave) or the third higher harmonic (double wave) to irradiate, except for the first harmonic of the solider laser, such as Nd:YAG laser, Nd:YLF laser, Yb:YAG laser, etc.. When these higher harmonics is in the wavelength range between 350~800nm, the amorphous film can appropriately absorb light and efficiently perform heating fusion.

Especially in the above-mentioned optical system for annealing, the linear irradiating beam which has a thin wide amplitude is formed on the silicon film surface. The irradiating beam scans the silicon film with the width of the beam in the direction orthogonal to the beam, heats it uniformly and rapidly, and then the silicon film is cooled to make it crystallize or grow up in the process of coagulation so that there is little interference pattern and the intensity distribution is uniform, whereby the crystal silicon film with wide amplitude, long shape and uniform high crystallinity is formed.

<u>Embodiment 1</u>

In the embodiment 1 of the present invention, an optical system for uniform irradiation of laser beam is shown in Fig. 1A and 1B, which can form the irradiating profile with the uniform

distribution extension in y direction and the straight-line form converged in x direction.

The optical system comprises a laser beam division unit 3, a superposition and irradiation unit 6 (61, 62). In this example, the laser beam division unit 3 divides a laser beam 1 into the divided beams 16a~16e with required quantity using a waveguide 4, and the divided beams are imaged as the irradiating beam 19 with straight-line profile on the irradiated area 90 by means of the superposition and irradiation unit 6.

In this embodiment, the laser beam division unit 3 comprises the optical system which makes the laser beam 1 from a laser oscillator incident in the waveguide 4, comprising an extender lens 31 for generating the collimated light, a y directional collimating lens 32 and a x directional collimating lens 33, and further comprising a condenser lens 34 (a cylindrical lens) which condenses the beams in y direction and makes them incident in the waveguide 4.

The opposite main surfaces of the waveguide 4 have reflecting faces 41 and 42, which are perpendicular to the y direction in this drawing. The laser beam 1 passes through the incident face 43 and the exit face 44 between two reflecting faces orthogonal to the optical axis of the laser beam. The incident laser beam 1 passing between reflecting faces is divided into: the divided beam component emitted from the exit end, two divided beam components (m=+1, m=-1) reflected once (m=1) from either of the reflecting faces 41 and 42, two divided beam components (m=+2, m=-2) reflected twice (m=2) from two reflecting faces, and each of components reflected 3 times or more and emitted from the exit end.

The divided beam from the waveguide 4 is superposed and projected on the irradiated area 90 by the superposition and irradiation unit 6. The superposition and irradiation unit 6 consists of a y directional duplication lens 61 (a cylindrical lens) which duplicates the divided beams in y direction on the irradiated area, and a condenser lens 62 (a cylindrical lens) which condenses the beams in x direction. The y directional duplication lens 61 makes the beams pass through the x directional condenser lens 62 and extend to the specified length in y direction on the irradiated area 90, and the x directional condenser lens 62 makes the beams converge into a line in x direction, whereby the irradiating beam 19 with a straight-line profile is obtained on the irradiated area.

More particularly, although Fig. 2 shows the form of the laser beam which is emitted from a laser oscillator (not shown) , divided by the waveguide used as the laser beam division unit, the laser beam from the laser oscillator passes through the condenser lens 34 (the cylindrical lens) and is incident in the waveguide 4 via a focus F_0. In the waveguide 4, a portion of the incident beam has the divided beams which aren't reflected from the reflecting face but pass through (reflection unmber m=0), and there are two kinds of the divided beams in y direction which are reflected once from the opposite reflecting face 41 or 42 (m=±1), and there are also two kinds of the divided beams in y direction which are reflected twice from the reflecting faces 41 and 42 (m=±2), and each of the divided beams are emitted from the exit face 44. In the surface which is perpendicular to the optical axis and contains the focus F_0, there are focuses of the virtual image, such as F_{+1}, F_{-1}, F_{+2}, and F_{-2}. It can be observed that each of the divided beams is emitted from

these focuses of the virtual image via the opening of the exit face 44.

In Fig. 2, supposing the beam profile obtained when the laser beam passes through the condenser lens 34 without the waveguide and is extended via the focus and projected on the exit face 44 is a circle, the projected laser beam 14 can be decomposed into the components corresponding to a plurality of classifications of the divided beams respectively. Each component of the laser beam 1 is in the cross section. If the division is performed in order of m=-2, -1, 0, +1, and +2 in y direction, then it should be noted that the components emitted from the exit face 44 of the waveguide 4, i.e. the divided beams, are arranged in order of reflection number m= +2, +1, 0, -1, and –2 in y direction.

In Fig.2, only the arrangement of the divided beams of the components of m=0, +1, and +2 emitted from the exit face 44 of the waveguide 4 is shown, and the divided beams of m= +1 and m= +2 are mutually emitted to an opposite direction relative to the median face of the reflecting faces. On the other hand, the divided beams of m=-1, -2 are in symmetrical direction relative to the divided beams of m=+1,+2, which is omitted in this figure.

Fig. 3A illustrates the division width of the divided beams obtained when the laser beam passes through focus F_0 without being reflected by the waveguide 4 and is projected on the corresponding area of the exit face 44 of the waveguide. It is an example that the laser beam 14 which follows the circular profile of the Gauss distribution is divided into 7 divided beams by the waveguide.

In the waveguide 4, the adjacent divided beams are superposed repeatedly on its exit face 44. Thus, the boundary portions of the adjacent components based on the division of the laser beam 1 in Fig. 3B are consistent with the repeated portions of the divided beams in the exit face of the waveguide. For example, in Fig. 3A, the boundary portion III of the component of m=+1 is overlapped repeatedly on the boundary portion iii of the adjacent component of m=0 in the exit face of the waveguide, as shown in Fig. 3B.

If such divided beams are superposed and irradiated on the irradiated area 90 by means of the y directional duplication leans 61 and the x directional condenser lens 62, the interference arises in the irradiating beam on the irradiated area and the intensity distribution is wavelike.

Fig. 4 shows the example of the intensity distribution of the irradiating beam 19 obtained when two components from the divided beams (such as two component of m=+1 and M=0) are superposed and irradiated on the irradiated area 90 by means of the y directional duplication leans 61 and the x directional condenser lens 62. However, the adjacent boundary portions iii and III of the divided beams from the laser beam interfere each other severely, and also the boundary portions IV and ii of the divided beams from the laser beam which are far from each other present a small variation of the intensity distribution caused by the interference. In Fig. 4, the horizontal axis is the division width d and the vertical axis is the relative beam intensity. But Fig. 4 is the case in which the intensity distribution of the laser beam is approximate to the Gauss distribution and the division width d is equal to the spatial interference distance s.

The interference level caused by the superposition on the irradiated area depends on the ratio of the division width d to the spatial interference distance s of the laser beam in this position. Here the spatial interference distance s is defined as the distance between the center of both of $1/e^2$ circle (e is the bottom of a natural logarithm here), wherein the beam diameter D is specified as the diameter D of the circle at the time of $1/e^2$ optical axis intensity ($1/e^2$ circle) when the intensity distribution in the cross section of the laser beam takes Gaussian distribution, as shown in Fig.5. Now the visibility of the interference fringe is reduced to 1/e in the superposed irradiation area when the optical axis is shifted each other from the interference condition in which their optical axis are in common. Here the visibility is the value obtained when the difference between the maximum intensity and the minimum intensity in the interfered intensity distribution is divided by the sum of the maximum intensity and the minimum intensity, which is indicative of the scale of the interference level.

When the division width d of the laser beam is d=s/2, the visibility is approximate to 1 in the superposition portion of the irradiating beam on the areas close to each other of the adjacent divided beams, while the visibility becomes 1/e in the superposition portion of the irradiating beam on the areas far from each other of the divided beams. In the median areas, the visibility will reduce gradually from 1 to 1/e. In a preferred embodiment, the division width d is d=s/2 or more, and at this moment, the visibility will be reduced to 1/e below in the superposition portion of the irradiating beam on the areas far from each other of the divided beams.

When the division width d of the laser beam is $d = s/\sqrt{2}$ or more, the visibility will be reduced to $1/e^2$ in the superposition portion of the irradiating beam on the areas far from each other of the divided beams. In a preferred embodiment, the visibility will be reduced to $1/e^4$ below in the superposition portion of the irradiating beam on the areas far from each other of the divided beams.

As shown in Fig.2, the division width d is made to be d=s and the laser beam is divided into 7 by the waveguide 4. Fig. 6 illustrates the intensity distribution when the divided beams are superposed on the irradiated area, which presents the improved intensity distribution. In this drawing, the period T of the generated interference fringes is determined by $T = \lambda / \sin \Delta\theta$, wherein λ is wavelength, and $\Delta\theta$ is the difference between the incident angles of two divided beams on the irradiated area 19 which can cause the interference.

Embodiment 2

In this embodiment, the cylindrical lens array is used as another kind of the beam division unit. As shown in Fig. 8A and 8B, the optical system for uniform irradiation of laser beam comprises the optical system which makes the laser beam 1 from the laser oscillator incident in the cylindrical lens array 5, comprising an extender lens 31 for generating the collimated light, a y directional collimating lens 32 and a x directional collimating lens 33, wherein the collimated light from the collimating lens 33 is incident in the cylindrical lens array 5.

In the cylindrical lens array 5, the cylindrical lens refers to the lens with the cylindrical shape in x

direction and the convex lens stacked in y direction toward the optical axis. However the cylindrical lens array in this example consists of five such tiny cylindrical lenses 5a~5e, whereby five divided beams are formed.

The divided beams 15a~15e from the cylindrical lens array 5 for beam division in y direction are incident in the cylindrical lens array 51 for further duplication disposed ahead, and the divided beams from the cylindrical lens array 51 for duplication are projected on the irradiated area 90 by means of the condenser lens 62 (the cylindrical lens) used to condense beam in x direction to form the irradiating beam 19 with a line-like profile that is uniform in y direction and is condensed into a thin line in x direction. An objective lens 63 is disposed between the cylindrical lens array 51 for duplication and the condenser lens 62.

Fig. 9A and 9B illustrate the division form of the laser beam using the cylindrical lens array 5. Different from the above-mentioned division using the waveguide, there is only the superposition without return when the beams divided by each of the tiny cylindrical lenses are superposed on the irradiated area. Thus, even though two adjacent divided beams are superposed on the irradiated area by means of the cylindrical lens array 51 for duplication and x directional condenser lens 62, there is no difference in the superposed intensity distribution in the interference of y direction.

Fig. 10 illustrates that the intensity distribution obtained by the superposition of two adjacent divided beams on the irradiated area is constant in y direction and its visibility is constant (i.e. 1/e) when the division width d is equal to the above spatial interference distance s.

Fig. 11 shows the intensity distribution obtained by the superposition of 7 divided beams which are divided by the cylindrical lens array 5 for division on the irradiated area, in which the division width d is d=s and there is a quite good distribution in y direction.

Embodiment 3

In the optical system according to an embodiment of the present invention, the uniformity unit comprises the optical delay unit which make one of the adjacent divided beams formed by the waveguide relative to the other be delayed a longer distance than the temporal interference distance of the laser beam. In order to prevent the interference occurring between the adjacent divided beams, the optical delay unit establishes the optical path difference between two adjacent divided beams, which is greater than the temporal interference distance.

This embodiment utilizes the optical delay unit, which shows the optical system utilizing the retardation plate with light transmission. As shown in Fig. 12A and 12B, the optical system uses the laser beam division unit 3 which utilizes the waveguide 4, two orthogonal cylindrical lenses (61,62) used as the superposition and irradiation unit 6, and the retardation plate 7 used as the optical delay unit. In this example, the waveguide 4 is the same as that of the embodiment 1, which divides the laser beam 1 into the divided beams 16a~16e with required quantity, and the divided beams are imaged as the irradiating beam 19 with straight-line profile on the irradiated area 90 by means of the superposition and irradiation unit 6.

In Fig. 12B, the retardation plate 7 (i.e. optical glass plate) used as the optical delay unit is inserted in any one of the divided beams apt to produce the interference mutually in the position where a plurality of the divided beams separate each other, thereby forming the optical path difference between the adjacent divided beams. In this example, the beams divided by the waveguide 4 are duplicated by the y directional duplication lens 61 and form the irradiating beam on the irradiated area by means of the x directional condenser lens 62, while the focus f of the beam is formed between the y directional duplication lens 61 and the x directional condenser lens 62 by means of the y directional duplication lens 61, and the glass plate used as the retardation plate 7 is inserted in the focal position f of either of the adjacent beams or front and rear of it to establish the optical path difference. In this example, the glass plates used as the retardation plates 7 are inserted in every other one of 5 divided beams while other divided beams will pass through the space between the adjacent retardation plates 7. By means of such an arrangement of the retardation plates 7, there is no interference between the adjacent divided beams occurring in the irradiating beam superposed on the irradiated area, thus essentially obtaining the profile of uniform intensity distribution.

The optical path difference $\triangle a$ of the glass plate is given by the thickness a of glass, the refractive index n_1 of glass and the refractive index n_0 of air (usually $n_0=1$). $\Delta a = (n_1 - n_0)/n_1$.

The optical path difference $\triangle a$ of the glass plate is set to be greater than the temporal interference distance $\triangle L$, that is, $\triangle a > \triangle L$, while the temporal interference distance of the laser beam is provided by $\Delta L = c\Delta t = \lambda^2 / \Delta\lambda$. Here c is light velocity and $\triangle t$ is interference time, and $\triangle\lambda$ is the wavelength width of the laser beam (spectrum width). The narrower the wavelength width of the laser beam is, the longer the interference distance is.

For example, in a Nd:YAG laser, for the beam with central wavelength $\lambda=1.06\mu m$, its spectrum width is $\triangle\lambda=0.12\sim0.30mm$, so the temporal interference distance is $\triangle L=3.8\sim9.4mm$.

Fig. 7 shows the relationship between the visibility of two divided beams from the adjacent regions of the laser beam on the irradiated area and the optical path difference established between the divided beams (i.e. the optical path difference $\triangle a$). When the optical path difference is equal to the temporal interference distance $\triangle L$, the visibility is reduced to 1/e, and the visibility will be further reduced by further increasing the optical path difference between the divided beams.

The glass thickness a, which provides the optical path difference between the adjacent divided beams more than the temporal interference distance $\triangle L$, can be obtained from these relationship. The thickness of the retardation plate can preferably provide the optical path difference which is 2 times or more of the temporal interference distance $\triangle L$, more preferably 4 times or more, by the configuration of the retardation plate. For example, the light source is the Nd:YAG laser, and when the retardation plate 7 as the optical delay unit uses quartz (its refractive index $n_1=1.46$), for the temporal interference distance $\triangle L=3.8\sim9.4mm$, the thickness of quartz glass a is 12~30mm.

Fig. 13 is a variant example of the embodiment 3, which illustrates the configuration of the optical system viewed from x direction. Except that the configuration of the optical delay unit 7 is different, the optical system for uniform irradiation of laser beam shown in Fig. 13 is substantially the same as those shown in Fig. 12A and 12B; however this system obstructs the divided beams that aren't reflected between the reflecting faces of the waveguide but pass through.

That is, the linear forward beams from the waveguide 4 shown in Fig.2, 3A and 3B with the reflection number m=0 are obstructed by a shelter 79 which is disposed in the focal position f behind the y directional duplication lens. Because the linearly forward beams with m=0 are blocked by the shelter 79 and can't reach the irradiated area, these beams make no contribution to the interference. So, the optical delay unit 7 is inserted in only either of groups of the divided beams (m=+1, -2) or (m=-1, +2) in symmetrical configuration, while no optical delay unit is inserted in the other group of the divided beams, whereby the interference between the divided beams on the irradiated area is alleviated. The optical delay unit 7 can use a single retardation plate 71 (such as a piece of glass plate or glass rod) to make one of groups of the divided beams (m=+1,-2) uniformly transmit, which has the advantage of simplifying the optical system.

The optical system in other variant example comprises the waveguide 4 and the optical delay unit 7. However the laser beam division unit formed from the waveguide doesn't involve the divided beams which aren't reflected in the waveguide 4 but linearly advance so that all of the divided beams are reflected at least once and the case in which the reflection numbers of two or more reflected beams are same is prevented. As shown in Fig. 14, such a laser beam division unit can take the structure which makes the optical axis of incident optical system of the laser beam division unit be at an oblique angle relative to the central axis of the waveguide.

As shown in Fig. 15,16A and 16B, supposing that the periphery component ① of the beams which are incident in the condenser lens 34 (the cylindrical lens) in the waveguide 4 is incident in the incident face of the waveguide 4 and then is reflected once from the reflecting face and emitted from the exit face; other beam components ②, ③, ④ from the condenser lens 34 are reflected twice, 3 times, 4 times respectively, and other components are reflected many times and emitted from the exit face. The emitted, divided beams are on the side of the exit face in Fig. 15 and indicated with the reflection numbers m=1~8.

Fig. 16A and 16B illustrate the configuration of the divided beams of the cross section of the laser beam in exit face 44 and the superposition of the divided beams in the exit face. The order of the reflection numbers indicates the order of the configuration of the divided beams in cross section of the laser beam. So, the divided beams with the order of the reflection number minus 1 are apt to interfere mutually on the irradiated area, and the retardation plate 7 as the spatial delay unit is disposed in either of the divided beams with order minus 1. As shown in Fig. 14, this retardation plate is disposed in the focal position f of the y directional duplication lens, and the group of the divided beams with even numbers of reflection (such as m=2,4,6) leans to one side relative to the group of the divided beams with odd numbers of reflection (such as m=1,2,3) so that a single retardation plate 72 is inserted in all of the divided beams with even numbers of reflection m=2,4,6.

In Fig. 16A and 16B, as described in above embodiment, the width d of the divided beam is set to be greater than or equal to 1/2 times of the spatial interference distance s, preferably $1/\sqrt{2}$ times or more, especially greater than or equal to 1 times of s.

Fig. 17 illustrates the other variant example in which no linearly forward divided beam is formed in the waveguide 4. In this example, the optical axis 40 of the waveguide 4 is made to be consistent with the optical axis 30 of the condenser lens 34 and the incident face 43 of the waveguide 4 is made to not be orthogonal to the optical axis but to be at an oblique angle. The incident beam 13 on the oblique incident face 43 is made to be refracted so that the divided beams reflected 1, 2, 3 etc. times other than the divided beams reflected 0 times can be obtained. In this example, by means of the focal position f of the y directional duplication lens, a single retardation plate 71 is inserted in the divided beams with the even numbers of reflection (such as m=2, 4, 6) or the divided beams with the odd numbers of reflection (such as m=1, 2, 3) in order to establish the optical path difference between the adjacent divided beams.

Embodiment 4

This embodiment illustrates the example in which the cylindrical lens array of the embodiment 2 is used as the division unit and the retardation plate is used as the optical delay unit that can delay the divided beams divided by the cylindrical lens array so as to prevent the interference.

In Fig. 18A and 18B, the retardation plate 7 as the optical delay unit is inserted in the divided beams 15a~15e divided by the cylindrical lens array 5 for division in y direction. In this example, each of the retardation plates 7 are inserted in every other one of the divided beams (i.e. the divided beams 15a, 15c, 15d) and no retardation plate is inserted in other divided beams 15b, 15d. Thereby, the interferences between the adjacent divided beams (for example, between the divided beams 15a and 15b, or between the divided beams 15b and 15c) on the irradiated area 90 are limited so as to make the intensity distribution caused by the interference of the superposed irradiating beam uniform.

Fig. 19 is a variant example of the optical system for uniform irradiation of laser beam shown in Fig. 18A and 18B, but a pair of the retardation plates 73 and 74 are disposed in the divided beams divided by the cylindrical lens array 5 for division and the focal position of the cylindrical lens array 51 for duplication in front of the cylindrical lens array 5 for division respectively. In this example, because two retardation plates 73 and 74 are disposed in front and rear of the cylindrical lens array 51 for duplication, the duplicated face and the duplicating face of the retardation plate are made to be conjugation relations, thus having the advantage of making the influence of diffraction on the irradiated area minimum.

Fig. 20 is a variant example of the optical system for uniform irradiation of laser beam shown in Fig. 18B, but the tiny lens 512 of the cylindrical lens array 51 for duplication in which the retardation plate 7 is inserted in the divided beams and the tiny lens 511 of the cylindrical lens array 51 for duplication in which no the retardation plate 7 is inserted in the divided beams are

made to have the different focal lengths so that their imagines on the irradiated area will became same. By means of inserting the retardation plate 7 for adjusting the optical path length in every other one of the divided beams arranged in y direction and divided by the cylindrical lens array 5 for division, the divided beams in which no retardation plate is inserted will result in the offset of the focal position f. However, the focal position of each tiny lens of the cylindrical lens array 51 for duplication can be used to compensate for the offset of the focal position f, thus making the intensity distribution of the interference caused by the superposed irradiating beam uniform.

Embodiment 5

In this embodiment, the optical rotatory unit is used as the uniformity unit to prevent the interference between the adjacent divided beams on the irradiated area and achieve uniformity. The optical system for uniform irradiation of laser beam comprises the waveguide used as the laser beam division unit, the cylindrical lens array used as the superposition and irradiation unit and the optical rotatory unit used as the uniformity unit. This optical system can form the irradiating profile with the uniform distribution extension in y direction and the straight-line form converged in x direction on the irradiated area. The laser beam division unit 3 utilizes the waveguide 4 to divide the laser beam into the divided beams with the required quantity and the superposition and irradiation unit makes the divided beams image as a straight-line profile on the irradiated area.

In the optical system of this embodiment, the uniformity unit comprises the optical rotatory unit which makes an angle of the polarization plane of either of the adjacent divided beams formed by the waveguide relative to the other essentially orthogonal. This optical rotatory unit can make the polarization planes of the adjacent divided beams mutually orthogonal to prevent the interference between the divided beams.

The optical rotatory unit performs optical rotation to make the relative angle of the polarization planes essentially orthogonal so that no interference arises between two adjacent divided beams. It is desirable to use the half-wavelength plate formed from quartz.

In Fig. 21A and 21B, the focus f is formed in front of the y directional duplication lens 61 (the cylindrical lens) before the waveguide 4 and the half-wavelength plate 8 used as the optical rotatory unit is disposed in this focal position. In this example, among the five divided beams from the waveguide 4, the half-wavelength plates 8 are inserted in only three divided beams with the reflection numbers m=0, m=+2 and m=-2, while no half-wavelength plate is inserted in the divided beams with other reflection numbers. Therefore, referring to Fig.2 and 3, the half-wavelength plate 8 is inserted in only either of two adjacent divided beams to make its polarization angle relative to the other divided beam essentially orthogonal. Thus, even though two adjacent divided beams which are combined at random are superposed on the irradiated area 90, there is no interference occurring between them. So, along with the limitation of the division width, the uniformity of the irradiating beam is improved by means of the superposition of the beams with essentially different polarization planes.

The use of the uniformity unit of this embodiment is to insert the half-wavelength plates 8 in every

other one of the divided beams in y direction, so it is necessary to provide the spacing between the half-wavelength plates 8 and 8 to make other divided beams pass through. The configuration and structure of this half-wavelength plate are somewhat complex.

In order to address this problem, in the structure shown in Fig. 22, the shelter 89 which is disposed in the focal position f at exit end of the y directional duplication lens 61 is used to obstruct the linearly forward beam with reflection number m=0. Since the linearly forward beam with m=0 can't reach the irradiated area, it doesn't contribute to the interference. So, a piece of half-wavelength plate used as the optical rotatory unit is inserted in either of groups of the divided beams (m=+1, -2) or (m=-1, +2) in symmetrical configuration relative to the linearly forward beam (m=0), while no the optical rotatory unit is inserted in the other group of the divided beams, whereby the interference between the divided beams 19 on the irradiated area is alleviated. On the other hand, the optical rotatory unit 8 can utilize a piece of half-wavelength plate 82 which makes one of groups of the divided beams (m=+1, -2) pass through together, which has the advantage of simplifying the optical system.

The shelter 89 can employ the solid which can absorb or reflect the laser beam, such as graphite, ceram, metal etc. The shelter 89 can also be assembled with a single optical rotatory unit 82 as a whole and be disposed in the focal position f of the y directional duplication lens 61.

In the variant example of Fig. 22, the center of the divided beam with m=0 is obstructed by the shelter 89. However, because the center of the divided beam with m=1 that is obstructed has the quite great energy, it will cause reduced efficiency without using it. It is uneconomical in this regard.

So, in the following variant example, the optical axis of the incident laser beam is made to intersect obliquely the central axis of the reflecting faces 41,42 of the waveguide relative to the waveguide so that the divided beams which aren't reflected between the reflecting faces 41,42 but pass through can't be generated, as shown in Fig. 14~16 of the embodiment 3. Then, the symmetry of the divided beams divided with reflection numbers m is destroyed, as shown in Fig.23, so that the divided beams from the waveguide vary from the divided beams reflected once (m=1) to the divided beams reflected many times (in this example, m=6) to prevent more than two divided beams from having the same number of reflection. Additionally, we can know from Fig. 23 that the divided beams with odd numbers of reflection m=1,3,5 and the divided beams with even numbers of reflection m=2,4,6 can be grouped into a group in the focal position f so that a single optical rotatory unit 8 can be used to simply configure the divided beams with odd numbers of reflection m=1,3,5 and the divided beams with even numbers of reflection m=2,4,6 without discarding the divided beams which aren't reflected (m=0) shown in Fig. 22. As shown in Fig.23, the polarization planes of the adjacent divided beams can be made to be essentially orthogonal by means of inserting a single optical rotatory unit 82 in the divided beams with even numbers of reflection, which has the advantage of preventing the interference between them in simple manner.

As other variant example of Fig. 23, the optical system shown in Fig. 24 comprises the waveguide 4 formed from the solid light-transmission body, which forms the incident face 43 of the

waveguide 4. The incident face 43 is not orthogonal to the central axis of the waveguide 4 but is appropriately oblique relative to the central axis so that the laser beam 12 from the condenser lens 34 on side of the light source is incident in the oblique exit face 43 and is refracted. As a result, the incident beam can be reflected at least once between the reflecting faces 41,42 and the divided beams which aren't reflected but pass through (m=0) aren't generated, as shown in Fig.23. The divided beams with gradually increasing reflection number can be established and then a single half-wavelength plate is used to divide the divided beams with even number of reflection or the divided beams with odd number of reflection to polarize these divided beams uniformly. At this moment, because the central axis of the waveguide is configured to be coaxial with the optical axis of the condenser lens 34, it is easy to design and assembly the optical system and it can achieve the same result as Fig.23.

In above described embodiment, the half-wavelength plate used as the optical rotatory unit is inserted in the adjacent divided beams to prevent the interference between them. However, the half-wavelength plate essentially prolongs the optical path length of the divided beam at same time so that the difference of the optical path lengths between the divided beam in which the half-wavelength plate is inserted and the divided beam in which no half-wavelength plate is inserted. In this way, if there is difference between the optical path lengths of two kinds of the divided beams, the imaging positions of the irradiating beams on the irradiating area are offset mutually so as to make the beam intensity profile on the irradiated area nondistinct, and the intensity distribution in width direction is extended, especially when the profile is a line form. Below, it is an example in which the optical path length compensating plate is inserted to prevent from generating the optical path difference.

In Fig. 25, the waveguide shown in Fig. 21B is used to divide beam and the half-wavelength plates 8 are inserted in every other one of the divided beams in the focal position f of the y directional duplication lens 61. In this example, the retardation plates 83 used as the optical path length compensating unit are inserted in the other of the divided beams in which the half-wavelength plates aren't inserted. In this example, the optical glass plate is used as the retardation plate 83, which thickness is set to produce the optical path length equal to that generated by the half-wavelength plate. There is no optical path difference between these divided beams generated on the irradiated area to guarantee distinctness of the irradiating profile.

Fig. 26 is an example in which the retardation plate 83 is applied to the example of Fig. 23. As above described, a single half-wavelength plate 82 is inserted in the group of the divided beams with even numbers of reflection (m=2, 4, 6) in the focal position f of the y directional duplication lens 61, while a single retardation plate 83 isn't inserted in the other of the divided beams with odd numbers of reflection (m=1, 3, 5), so as to eliminate the optical path difference between the beam groups. The special advantage of this example is to take a single half-wavelength plate 82 and a single retardation plate 83 as a whole, thus simply disposing them in the focal position f.

Embodiment 6

This embodiment is an example of the optical system for uniform irradiation of laser beam, in which the optical rotatory unit is used as the uniformity unit and the cylindrical lens array is used

as the laser beam division unit.

Fig. 27 shows the optical system which makes the laser beam 1 from the laser oscillator (not shown) incident in the cylindrical lens array 5. The optical system comprises the extender lens 31 for generating the collimated light, a y directional collimating lens 32 and a x directional collimating lens 33, wherein the collimated light from the collimating lens 33 is incident in the cylindrical lens array 5. The cylindrical lens array 5 refers to the lens with the cylindrical shape in x direction and the convex lens stacked in y direction toward the optical axis, which consists of five tiny cylindrical lenses 5a~5e, whereby five divided beams 15a~15e are formed.

The divided beams from the cylindrical lens array 5 for division in y direction are incident in the cylindrical lens array 51 for further duplication disposed ahead, and the divided beams from the cylindrical lens array 51 for duplication is projected on the irradiated area 90 by means of the condenser lens 62 (the cylindrical lens) used to condense beam in x direction to form the irradiating beam 19 with a line-like profile that is uniform in y direction and is condensed into a thin line in x direction. The objective lens 63 is disposed between the cylindrical lens array 51 for duplication and the condenser lens 62.

The half-wavelength plate 8 used as the optical rotatory unit is inserted in the divided beams 15a~15e divided by the cylindrical lens array 5 for division in y direction. However, the half-wavelength plates 7 are inserted in every other one of the divided beams (i.e. the divided beams 15a, 15c, and 15d) and no half-wavelength plate is inserted in other divided beams 15b, 15d. Thereby, the polarization angle between the adjacent divided beams (for example, between the divided beams 15a and 15b, between the divided beams 15b and 15c or other adjacent divided beams) is essentially orthogonal so as to suppress the interference on the irradiated area 90, thus making the intensity distribution caused by the interference of the superposed irradiating beam 19 uniform.

Other variant example is the example in which the half-wavelength plate includes the optical path length compensating unit. Fig.28 is an example in which the retardation plate 83 made of glass as the optical path length compensating unit is inserted in the corresponding other of the divided beams where no optical rotatory unit is inserted in (in this example, 15d, 15d). As above described, the half-wavelength plate 8 used as the optical rotatory unit is disposed in one of the divided beams, but the insertion of the half-wavelength plate 8 prolongs the optical path length of this divided beam. If there is difference between the optical path lengths of two kinds of the divided beams, the imaging positions of the irradiating beams on the irradiating area are offset mutually so as to make the profile nondistinct. In order to correct it, the retardation plate 83 used as the optical path length compensating unit which is used to prolong the optical path length is inserted in the other of the divided beams. In this example, the thickness of the optical glass plate used as the retardation plate 83 is set to produce the optical path length equal to that generated by the half-wavelength plate 8. Because the half-wavelength plate 8 and the retardation plate 83 are disposed alternately in Fig.27, the integrative uniformity unit can be formed by alternately connecting the half-wavelength plate 8 and the retardation plate 83 and taking them as a whole.

Fig. 29 is an example which, in the cylindrical lens array 51 for duplication of the optical system for uniform irradiation of laser beam shown in Fig. 27, the tiny lens 512 which the half-wavelength plate 7 is inserted in the divided beams and the tiny lens 511 which no the half-wavelength plate 7 is inserted in the divided beams are made to have the different focal lengths so that their imagines on the irradiated area will became same. By means of inserting the half-wavelength plate 8 for rotating the polarization plane in every other one of the divided beams arranged in y direction and divided by the cylindrical lens array 5 for division, the divided beams in which no half-wavelength plate is inserted will result in the offset of the focal position f. However, the focal position of each tiny lens of the cylindrical lens array 51 for duplication can be used to compensate for the offset of the focal position f, thus making the intensity distribution of each divided beam to be imaged on the irradiated area uniform.

Embodiment 7

In this embodiment, the optical system for irradiation of laser beam consists of the laser beam division unit which can divide the laser beam from the laser source, and the superposition and irradiation unit which can make the divided beams superposed and irradiated on the irradiated area. When the superposition and irradiation unit duplicates each of the divided beams on the irradiated area, each of the divided beams will be misaligned (i.e. shifted) mutually to form the irradiating beam.

In this embodiment, the waveguide is used as the laser beam division unit. The superposition and irradiation unit makes the divided beams from the laser beam division unit offset mutually and irradiate the irradiated area 90, thereby preventing the interference between the divided beams on the irradiated area so as to obtain the uniformity of the irradiating beam.

In this embodiment, in Fig. 30A and 30B, the laser beam division unit comprises the optical system which makes the laser beam 1 from the laser oscillator incident in the waveguide 4, comprising an extender lens 31 for generating the collimated light, a y directional collimating lens 32 and a x directional collimating lens 33, and further comprising the condenser lens 34 (the cylindrical lens) which condenses the beams in y direction and makes them incident in the waveguide 4.

The opposite main surfaces of the waveguide 4 have reflecting faces 41 and 42, which are perpendicular to the y direction in this drawing, and the incident face 43 and the exit face 44 are orthogonal to the optical axis (in parallel with y direction). We can know from the above embodiment 1 in Fig. 2 and 3 that the laser beam 1 incident in the incident face 43 is divided into the component which isn't reflected from the reflecting face but passes through (m=0) and the component which is reflected from the reflecting face, in which the reflected component is divided into the component reflected once (m=1), the component reflected twice (m=2) and the component reflected three times.

The divided beam from the waveguide 4 is superposed and projected on the irradiated area 90 by the superposition and irradiation unit 6. The superposition and irradiation unit 6 consists of a y directional duplication lens 61 (cylindrical lens) which duplicates the divided beams in y direction

on the irradiated area, and a condenser lens 62 (cylindrical lens) which condenses the beams in x direction.

The y directional duplication lens 61 makes the beams pass through the x directional condenser lens 62 and extend to the specified length in y direction on the irradiated area 90, and the x directional condenser lens 62 makes the beams converge into a line in x direction, whereby the irradiating beam 19 with a straight-line profile is obtained on the irradiated area.

In this embodiment, as shown in Fig. 30B, the superposition and irradiation unit utilizes the aberration of the duplication lens 61 disposed in front of the waveguide 4 to make each of the divided beams 16a~16s somewhat misalign mutually and irradiate in y direction, thereby making the superposition of two tips of the superposed irradiating beam 19 in y direction on the irradiated area be misaligned so that its intensity distribution is step-like as shown in Fig. 30C. This alleviates large interference, and the irradiating beam with uniform intensity and less interference can be obtained in the range of uniform irradiation.

As the embodiment 3 shown in Fig. 14, in the example of Fig. 31A and 31B, the waveguide 4 is made of the transparent solid, in which its incident face 43 intersects obliquely its axial direction so that the incident beam is refracted. The beam reflected once from the reflecting face (m=1), the beam reflected twice (m=2), the beam reflected three times (m=3), and even the beam reflected six times (m=6) are emitted from the exit face, and the divided beams are made to irradiate the irradiated area 90 by means of the y directional condenser lens 61 and the x directional condenser lens 62. However, same as Fig. 30A and 30B, the divided beams are made to be misaligned and irradiate in y direction on the irradiated area 90 of the drawing by means of the lens aberration of the y directional condenser lens 61, thereby preventing the interference between the divided beams on the irradiated area so as to obtain the uniformity of the irradiating beam.

The following variant example illustrates the optical system for laser beam irradiation in which each of the divided beams are offset mutually and duplicated to form the irradiating beam on the irradiated area by the superposition and irradiation unit in the optical system comprising the cylindrical lens array as the laser beam division unit.

Fig. 32A and 32B comprise the extender lens 31 for amplifying the laser beam, the y directional collimating lens 32 and the x directional collimating lens 33, so that the collimated light is incident in the cylindrical lens array 5. The divided beams 15a~15e divided by the cylindrical lens array 5 form the irradiating beam 19 with line-like profile extending in y direction on the irradiated area by means of the cylindrical lens array 51 for duplication, the y directional objective lens (the cylindrical lens) 63 and the x directional condenser lens 62. Furthermore, the objective lens 63 is adjusted to make the divided beams 16a~16e from the laser beam division unit be misaligned mutually and irradiate the irradiated area 90 to obtain the irradiating beam 19, thereby preventing the interference between the divided beams on the irradiated area so as to obtain the uniformity of the irradiating beam in y direction. Then, as shown in Fig. 30C, the irradiation profile at two tips in y direction presents the step-like intensity distribution, which enables the range of the irradiating beam with uniform distribution to be obtained.

As shown in Fig.33A and 33B, in the variant example of this embodiment, the retardation plate 7 used as the optical delay unit is disposed between the cylindrical lens array 5 for division and the cylindrical lens array 51 for duplication to alleviate the interference caused by the adjacent divided beams on the cross section of the laser beam on the irradiated area. The effect of the reduced interference caused by the offset of each of the divided beams when superposed, which is produced by the objective lens 63, along with the effect of the reduced interference between the divided beams caused by the optical delay, enable this example to have the advantage of further reducing the variation in the intensity distribution caused by the interference.

In this embodiment, in the optical delay unit, the retardation plates 7 with light transmission are disposed in every other one of a plurality of the divided beams. The optical path difference which is greater than the spatial interference distance can be formed between the adjacent divided beams by making either of the adjacent divided beams pass through the retardation plate 7.

The following example illustrates the polarization unit which is used in the uniformity unit to make one of the adjacent divided beams essentially orthogonal relative to the polarization direction of the other. In the example shown in Fig. 34, the laser beam from the laser source first passes through the optical rotatory plate 71 to the extender lens 31, and the half-wavelength plates 8 used as the optical rotatory plate are inserted in the divided beams 15a~15e divided by the cylindrical lens array 5 for division in y direction. However, the half-wavelength plates 7 are inserted in every other one of the divided beams 15a, 15c, 15d and no half-wavelength plate is inserted in other divided beams 15b, 15d. Thereby, the polarization angle between the adjacent divided beams (for example, between the divided beams 15a and 15b, between the divided beams 15b and 15c or other adjacent divided beams) is essentially orthogonal so as to suppress the interference on the irradiated area 90, thus making the intensity distribution caused by the interference of the superposed irradiating beam 19 uniform. In this example, the half-wavelength plates 7 are inserted in every other one of the beams divided in y direction so that the polarized light irradiates the irradiated area 90 by means of the duplication lens. But, here the objective lens 63 is adjusted to make each of the divided beams be misaligned in y direction, thereby preventing the interference between the divided beams. When the misaligned beams irradiates the irradiated area 90, the intensity distribution of the irradiating beam 19 is step-like at two tips of the irradiating beam 19 in y direction but the uniform intensity distribution with less interference can be achieved in major portion other than two tips.

What is claimed is:

1. An optical system for uniform irradiation of laser beam, comprising:

a laser beam division unit which divides the laser beam form a laser source into the divided beams spatially in a beam cross section; and

a superposition and irradiation unit which makes the divided beams superposed and irradiated on an irradiated area;

characterized in that the laser beam division unit makes the width of the divided beam greater than or equal to 1/2 times of a spatial interference distance in cross section direction of the laser beam cross section.

2. The optical system according to claim 1, wherein the division width of the laser beam is greater than or equal to the spatial interference distance.

3. An optical system for uniform irradiation of laser beam, comprising:

a laser beam division unit which divides the laser beam form a laser source into the divided beams spatially in a beam cross section;

a superposition and irradiation unit which makes the divided beams superposed and irradiated on an irradiated area; and

an uniformity unit which makes the beam intensity on the irradiated area uniform;

characterized in that the uniformity unit comprises an optical delay unit which makes one of the adjacent divided beams relative to the other be delayed a longer distance than a temporal interference distance of the laser beam.

4. The optical system according to claim 3, wherein the optical delay unit is a retardation plate disposed in the region which separates a plurality of the divided beams spatially.

5. The optical system according to claim 4, wherein the laser beam division unit is a one-dimensional waveguide with the opposite reflecting faces, and the superposition and irradiation unit comprises a duplication lens for duplicating the divided beams from the laser beam division unit on the irradiated area, and each of the retardation plates is disposed about the focal position of the duplication lens for the divided beams.

6. The optical system according to claim 5, wherein the optical axis of the incident laser is configured to intersect obliquely the central axis between the reflecting faces of the waveguide relative to the waveguide so that the beams which aren't reflected but pass through can't be generated between the reflecting faces, thereby making either of two group of the adjacent irradiating beams pass through a single retardation plate.

7. The optical system according to claim 4, wherein the laser beam division unit is a one-dimensional cylindrical lens array for dividing the laser beam;

the retardation plates are disposed in the regions which separate spatially the plurality of the divided beams formed by the cylindrical lens array for division.

8. An optical system for uniform irradiation of laser beam, comprising:

a laser beam division unit which divides the laser beam form a laser source into the divided beams spatially in a beam cross section;

a superposition and irradiation unit which makes the divided beams superposed and irradiate an irradiated area; and

an uniformity unit which makes the beam intensity on the irradiated area uniform;

characterized in that the uniformity unit comprises an optical rotatory unit which makes the polarization direction of one of the adjacent divided beams relative to the other essentially orthogonal.

9. The optical system according to claim 8, wherein the optical rotatory units are disposed in the regions which separate spatially the plurality of the divided beams to make the polarization direction of either of the spatially separate, adjacent divided beams essentially orthogonal.

10. The optical system according to claim 8 or 9, wherein the laser beam division unit is a one-dimensional waveguide with the opposite reflecting faces, and the superposition and irradiation unit comprises a duplication lens for duplicating the divided beams from the laser beam division unit on the irradiated area, and the optical rotatory plate is disposed in the focal position of the duplication lens for the divided beams.

11. The optical system according to claim 10, wherein the optical axis of the incident laser intersects obliquely the central axis between the reflecting faces of the waveguide so that the divided beams which aren't reflected but pass through can't be generated between the reflecting faces.

12. The optical system according to claim 8 or 9, wherein the laser beam division unit is a one-dimensional cylindrical lens array for dividing the laser beam and the optical rotatory plates are disposed in the regions which separate spatially the plurality of the divided beams formed by the cylindrical lens array for division to make the polarization direction of either of the adjacent divided beams relative to the other essentially orthogonal.

13. The optical system according to claim 8 or 9, wherein an optical path length compensating plate is disposed in the other of the adjacent divided beams to make the optical path length of the other of the adjacent divided beams essentially equal to that of the one of the adjacent divided beams.

14. An optical system for uniform irradiation of laser beam, comprising:

a laser beam division unit which divides the laser beam form a laser source into the divided beams spatially in a beam cross section; and

a superposition and irradiation unit which makes the divided beams superposed and irradiate an irradiated area;

characterized in that the superposition and irradiation unit makes each of the divided beams be misaligned mutually and duplicated on the irradiated area to form an irradiating beam.

15. The optical system according to claim 14, wherein the laser beam division unit comprises a one-dimensional waveguide with the opposite reflecting faces or cylindrical lens array for division, and the superposition and irradiation unit is a cylindrical lens with the lens aberration.

Abstract

An optical system for uniform irradiation of laser beam is provided. The optical system includes a waveguide which divides spatially the laser beam from a laser source into the divided beams, a lens for superposition which makes the divided beams superposed and irradiated on an irradiated area, and a retardation plate which makes the beam intensity on the irradiated area uniform. The waveguide makes the width of the divided beam more than 1/2 times of the spatial interference distance in cross section direction of the laser beam cross section. The retardation plate makes the delay of the adjacent divided beams longer than the temporal interference distance of the laser beam, thereby alleviating the interference on the irradiated area. Another optical system includes a laser beam division unit which divides the laser beam into the divided beams, a superposition and irradiation unit which makes the divided beams superposed and irradiated on an irradiated area; and an uniformity unit which makes the beam intensity on the irradiated area uniform. The uniformity unit includes an optical delay unit which makes the delay between the adjacent divided beams longer than the temporal interference distance of the laser beam. The uniformity unit further includes an optical rotatory unit which makes the polarization direction between the adjacent divided beams essentially orthogonal.

Reference Number:

Fig. 1A

聚光方向（x 方向）condensing beam direction (x direction)

Fig. 1B

均匀化方向（y 方向）uniformity direction (y direction)

Fig. 3B

均匀化 uniformity

Fig. 4

光强度分布（相对值） light intensity distribution (the relative value)

m=+1 和 m=0 的组合 combination m=+1 and m=0

可见度 visibility

重合的光束在 y 方向的照射面上的位置 the position of the superposed beam on the irradiated area in y direction

Fig. 5

可见度 visibility

Fig. 6

光强度分布（相对值） light intensity distribution (the relative value)

重合的光束在 y 方向的照射面上的位置 the position of the superposed beam on the irradiated area in y direction

Fig. 7

可见度 visibility

光程差 optical path difference

距离 distance

Fig. 8A

聚光方向（x 方向）condensing beam direction (x direction)

Fig. 8B

均匀化方向（y 方向）uniformity direction (y direction)

Fig. 9B

均匀化 uniformity

Fig. 10

光强度分布（相对值） light intensity distribution (the relative value)

ii-III 和 iii-IV 的组合 combination ii-III and iii-IV

可见度 visibility

重合的光束在 y 方向的照射面上的位置 the position of the superposed beam on the irradiated area in y direction

Fig. 11

光强度分布（相对值） light intensity distribution (the relative value)

重合的光束在 y 方向的照射面上的位置 the position of the superposed beam on the irradiated area in y direction

Fig. 12A, 18A, 21A, 27A, 30A, 31A, 32A, 33A

聚光方向（x 方向）condensing beam direction (x direction)

Fig. 12B, 13, 14, 17, 18B, 19,20, 22, 23, 24, 25, 26, 27B, 28, 29, 30B, 31B, 32B, 33B, 34

均匀化方向（y 方向）uniformity direction (y direction)

Fig. 16B

均匀化方向 uniformity direction

Fig. 30C, 31C

照射强度 irradiation intensity

均匀照射的范围 range of uniform irradiation

Y 方向位置 position in y direction